Analysis of Nitrogen Loading Reductions for Wastewater Treatment Facilities and Non-Point Sources in the Great Bay Estuary Watershed

Appendix B:

<u>Nitrogen Loading Thresholds for the Great Bay Estuary</u>

NEW HAMPSHIRE DEPARTMENT OF Environmental Services

DRAFT

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Attachments

1 Introduction

In 2009, the New Hampshire Department of Environmental Services (DES) published a proposal for numeric nutrient criteria for the Great Bay Estuary (DES, 2009). These criteria were developed over a four-year period through an open process that involved local experts from universities, state agencies, federal agencies, municipalities, and non-governmental organizations. The report found that total nitrogen concentrations in most of the estuary needed to be less than 0.3 mg/L to prevent loss of eelgrass habitat and less than 0.45 mg/L to prevent occurrences of low dissolved oxygen. Eelgrass habitat and dissolved oxygen are both critical for supporting aquatic life in the Great Bay Estuary.

Based on these criteria and an analysis of a robust compilation of data from multiple sources, DES concluded that 11 of the 18 assessment zones in the Great Bay Estuary did not meet surface water quality standards and specifically did not comply with Env-Wq 1703.14, the narrative standard for nutrients (DES, 2009b). These impairments were added to New Hampshire's 2008 303(d) list on August 14, 2009, approved by EPA on September 30, 2009, and have subsequently been retained on the 2010 303(d) list. Nine of the 11 impaired assessment zones were the subestuaries of Great Bay, Little Bay, Upper Piscataqua River, and the tidal rivers that flow into these areas. The other two impaired assessment zones were Portsmouth Harbor and Little Harbor/Back Channel at the mouth of the estuary.

Under the Clean Water Act, if a water body is placed on the 303(d) list, a study must be completed to determine the existing loads of the pollutant and the load reductions that would be needed to meet the water quality standard. However, there are no pre-existing models from which the nitrogen loading thresholds for the Great Bay Estuary could be estimated.

For this analysis, the nitrogen loading thresholds associated with meeting water quality standards were determined for the subestuaries of Great Bay, Little Bay, Upper Piscataqua River, and the tidal rivers that flow into these areas. Thresholds were determined using a steady state, mass balance model for three two-year periods: 2003-2004, 2005-2006, and 2007-2008. The precipitation varied across these periods with total amounts of 46, 68, and 60 inches in 2003-2004, 2005-2006, and 2007-2008. Three different loading thresholds were calculated for each subesutary: The nitrogen load to prevent low dissolved oxygen locally; the nitrogen load to protect eelgrass locally; and the nitrogen load to protect eelgrass in downstream areas. The impaired assessment zones of Portsmouth Harbor and Little Harbor/Back Channel were not included in this assessment because of the high salinity and complex hydrology in these areas which necessitates a different modeling approach.

2 Methods

The basic premise employed to calculate nitrogen loading thresholds for the Great Bay Estuary was that steady state concentrations of nitrogen in an estuary will be equal to the nitrogen load divided by the total water flushing rate from freshwater and ocean water. Estuaries are complicated systems with variability due to tides, weather, and stream flows. However, by making the steady state assumption, it is not necessary to model all of these factors. The steady state assumption can be valid for calculations based on annual or multi-year average conditions which approximate steady state conditions. Therefore, calculations for this analysis were made using average values for three two-year periods: 2003-2004, 2005-2006, and 2007-2008.

The nitrogen loading threshold calculation was completed in three steps. First, fresh water inputs to each subestuary were computed. Second, ocean water inputs to each subestuary were estimated using salinity measurements in the subestuary and the fresh water inputs. Finally, the total water flushing rate was combined with the numeric criteria for total nitrogen to calculate the nitrogen loading thresholds to support designated uses.

The nitrogen threshold calculations were limited to the ten subestuaries upstream from Dover Point: the Winnicut, Squamscott, Lamprey, Oyster, Bellamy, Cocheco, and Salmon Falls rivers as well as the Great Bay, Little Bay, and Upper Piscataqua River. With the exception of the Winnicut River subestuary, all of these subestuaries are impaired for nitrogen. The Winnicut River subestuary was included in the calculations, even though it was not impaired for nitrogen, because it discharges to the Great Bay, which is impaired. Nitrogen loading thresholds were not calculated for the Lower Piscataqua River, Portsmouth Harbor, and Little Harbor/Back Channel because the salinities in these subestuaries were too similar to ocean water. If there is not much of a salinity difference between the subestuary and the ocean, the ocean water inputs calculation can be inaccurate. Table 1 contains the watershed drainage areas and other information for the ten subestuaries included in these calculations. Maps of each of the subestuaries are provided in Figures 1 through 11.

2.1 Fresh Water Inputs to Subestuaries

2.1.1 Fresh Water from Watersheds above Tidal Dams

All of the major watersheds to the estuaries have head-of-tide dams. The stream flow passing over these dams and into the estuary was estimated from U.S. Geological Survey (USGS) stream gages in the watersheds or similar watersheds. Average daily flow in the Lamprey, Exeter, Oyster, Cocheco, and Winnicut rivers were estimated from USGS stream gages 01073500, 01073587, 01073000, 01072800, and 01073785, respectively. For these rivers, flow at the head-of-tide station was estimated by multiplying the flow at the gage by the ratio of the watershed area upstream of the head-of-tide station to the watershed area upstream of the gage. Flows in the Bellamy River were estimated using area transpositions from the Oyster and Cocheco river streamgages. Specifically, the average flow per square mile (cubic feet per second per square mile or CFSM) at the Oyster River streamgage was multiplied by the watershed area for the Bellamy River to obtain one estimate of the flow in the Bellamy. The average flow per square mile at the Cocheco River streamgage was also multiplied by the Bellamy watershed area to obtain another estimate of the flow. Finally, the two estimates of flow were averaged. Flows in the Salmon Falls River and Great Works River were estimated using area transpositions from the average flow per square mile from the Lamprey River and Cocheco River, respectively. The watershed areas and flow transposition factors are listed in Table 2. Known water withdrawals upstream of the gages were added to the measured streamflows before calculating the CFSM values so that runoff estimates would not be biased low. The measured stream flows at the gages, upstream water withdrawals, corrected stream flow values, and estimated stream flows at the head-of-tide dams are shown in Table 3, Table 4, Table 5, and Table 6, respectively. Known net withdrawals between the stream gage and the tidal dam were accounted for in Section 2.1.6.

2.1.2 Fresh Water from Watersheds below Tidal Dams

Runoff from the watershed land areas downstream of the head-of-tide dams also contributes fresh water to the subestuaries. The volume of runoff contributed was calculated using the average flow per square mile (CFSM) from the watershed above the dam (corrected for withdrawals upstream of the gages) multiplied by the land area in the watershed below the dam. For coastal drainage areas surrounding the Great Bay, Little Bay, and the Upper Piscataqua River, the average flow per square mile from all of the contributing watersheds was used. For example, for the drainage area immediately surrounding Great Bay, the predicted flow from the Winnicut, Exeter, and Lamprey rivers from Section 2.1.1 was summed and then divided by the sum of the drainage areas for these three watersheds to calculate the average CFSM.

2.1.3 Fresh Water from Precipitation to Subestuary Surface Area

Precipitation in the watershed was accounted for through the estimates of fresh water from watershed land areas. However, precipitation directly onto the estuary surface was not. To estimate the freshwater contribution for this pathway the average annual precipitation rate from four weather stations in the Great Bay Estuary watershed (Table 7) was multiplied by the surface area of the estuary. This total was reduced by 10% to account for losses back to the atmosphere through evaporation. The USGS has reported the average evapotranspiration rate for the Piscataqua Region watersheds to be 20 inches per year, which is slightly less than half of the average precipitation rate (Randall, 1996). This rate of evaporative losses is too high for the estuary because the water temperatures are typically low and transpiration will be limited. Therefore, DES assumed an evaporative loss rate of 10% for precipitation directly to the estuary surface.

2.1.4 Fresh Water from Wastewater Effluent Discharges

For estuaries with wastewater discharges directly to the tidal waters, the volume of wastewater discharged was added to the fresh water inputs. The wastewater inputs were often, but not always, approximately equal to the water supply withdrawals in the upstream watershed which is reflected in the USGS gage data.

2.1.5 Fresh Water from Groundwater

Ballestero et al. (2004) measured a groundwater seepage rate along the shoreline of Great Bay in 2000 and 2001. The groundwater seepage rate was determined to be between 0.12 and 0.17 cfs per mile of shoreline using two different methods. To estimate the total groundwater contribution to each subestuary the length of tidal shoreline for each subestuary was calculated and then multiplied by 0.15 cfs/mi. DES assumed that the groundwater seepage rate was constant for all periods because there was no way to credibly vary the inputs for different years.

2.1.6 Net Loss of Fresh Water from Large Water Withdrawals

Large water withdrawals that transfer water between watersheds have the potential to alter the freshwater inputs to the estuary. For example, the Portsmouth water supply receives significant volumes of water from the Bellamy, Oyster, and Winnicut watersheds. This water is discharged through the Portsmouth wastewater treatment facility to Portsmouth Harbor instead of the tidal rivers in the watersheds where it originates. The methods for estimating streamflow and runoff would over predict freshwater inputs if these water withdrawals were not taken into account.

For this model, DES chose to just account for water withdrawals for municipal water supplies because these types of withdrawals tend to be the largest and have the capacity to be discharged outside of the watershed in which they originate. All of the registered water users for water supply in the Great Bay Estuary were selected using GIS techniques. Based on the water user name, municipal withdrawals were selected from this list. DES queried the Water User database to obtain the annual average water use in 2002 through 2008 for each of these users. If the annual water use values were incomplete for a user (e.g., a year or years of missing data), the average water use between 2002 and 2008 was substituted for the missing value(s). Water users without data in the database were not used in calculations. Tables 8 and 9 summarize the average water withdrawals from each of the watersheds in 2003 through 2008.

The effects of these water withdrawals were accounted for in two ways. First, withdrawals upstream of USGS stream gages were used to correct the CFSM value for stream flow estimates (as discussed in Section 2.1.1). If these withdrawals were not added back to the flow measured at the gage, the CFSM value would be biased low which would underestimate runoff volumes for the watershed. Second, withdrawals from the watershed that were discharged to the estuary were subtracted off the freshwater budget for each subestuary. A typical example of such a withdrawal would be a municipal water supply well in the watershed which was discharged as wastewater from a WWTF directly to the estuary. Since the CFSM was corrected for any upstream withdrawals, the runoff estimates represent what would be expected in the absence of any withdrawals in the whole watershed (both upstream and downstream of the gage). Withdrawals that are not returned to the river needed to be subtracted from the fresh water budget to account for these losses. The return of the water to the estuary was accounted for by adding the volume of wastewater discharged (see Section 2.1.4). In cases where the withdrawal was discharged elsewhere (e.g., to Portsmouth Harbor), the water was never returned to the estuary. If a withdrawal was discharged within the watershed (e.g., there was a WWTF outfall on the upstream side of the tidal dam river), the withdrawal was not subtracted from the water budget because the water was returned to the stream, not the estuary.

2.1.7 Total Fresh Water Inputs

The total fresh water input to a subestuary was calculated as the sum of stream flow and runoff from watersheds, precipitation to the estuary surface, wastewater discharges, and groundwater, minus any water withdrawals from the watershed.

The interconnected nature of the tidal rivers and bays in the Great Bay Estuary required nested calculations for the Great Bay, Little Bay, and Upper Piscataqua River subestuaries. For these subestuaries, the total fresh water inputs were the sum of the inputs from contributing watersheds plus inputs directly to the water body that were not accounted for in the contributing watersheds. For example, the total fresh water inputs to Great Bay was the sum of the inputs to the Winnicut, Exeter, and Lamprey subestuaries plus runoff from shorelands immediately surrounding Great Bay, precipitation to the Great Bay surface, and groundwater discharge along the Great Bay shoreline. The contributing areas for Great Bay, Little Bay, and the Upper Piscataqua River are summarized in the following table.

Subestuary	**Contributing Watersheds**
Great Bay	Winnicut River, Exeter River, Lamprey River, shoreland areas surrounding Great Bay
Little Bay	Great Bay, Oyster River, Bellamy River, shoreland areas surrounding Little Bay
Upper Piscataqua River	Cocheco River, Salmon Falls River, shoreland areas surrounding the Upper Piscataqua River

2.2 Ocean Water Inputs to Subestuaries

The tidal exchange in a subestuary was estimated from the salinity in the subestuary, the salinity in the ocean, and the fresh water inputs to the subestuary using an equation from Fischer et al. (1979). Steady state conditions must be assumed for this calculation. This assumption was valid because the calculations were made using multi-year average conditions which approximate steady state.

The salt balance for a subestuary requires that the product of the ocean water input and ocean salinity be equal to the salinity of the subestuary multiplied by the sum of the ocean water and fresh water inputs. This equation can be rearranged and solved for the ocean water input rate:

$$Q_o = Q_{fw} * \frac{S}{S_o - S}$$

where Q_o is the ocean water input, Q_{fw} is the total fresh water input, S_o is the salinity of the ocean water, and S is the steady state (or long term average) salinity in the subestuary. Q_{fw} was derived using the methods in the previous section which calculated the total fresh water inputs to the subestuary. The salinity of ocean water, S_o, was estimated to be 31.6 ppt from the median of surface samples from Wilkinson Basin Transect stations WB1 and WB2 in 2005-2007 (all available relevant data from the Gulf of Maine offshore of Portsmouth Harbor).

The salinity in each subestuary during each period was determined using all available salinity measurements from the DES Environmental Monitoring Database. In Table 10, the average values from grab samples and datasondes within each subestuary have been compiled. However, the appropriate salinity value was ultimately chosen using maps of average salinities at each station within each subestuary (Attachments A, B, and C). It was important to use this approach to select a central location within each subestuary or the location of maximum eelgrass extent to model. In Table 10, the average salinity in a central location of each subestuary has been listed along with the station or stations that mark the chosen central location.

Once calculated, the ocean water input was combined with total fresh water inputs to determine the total water inputs to each subestuary.

2.3 Nitrogen Loading Threshold Calculation

The purpose for estimating the total water inputs for each subestuary was to determine the maximum allowable nitrogen loading which, when diluted by the water inputs, would result in steady state concentrations equal to the numeric criteria for nitrogen. Three different loading thresholds were calculated for each subesutary: The nitrogen load to prevent low dissolved oxygen locally; the nitrogen load to protect eelgrass locally; and the nitrogen load to protect eelgrass in downstream areas.

2.3.1 Nitrogen Loading Threshold to Prevent Low Dissolved Oxygen in the Subestuary

The first step of the threshold calculation was to calculate the nitrogen concentration in the estuary associated with ocean water and to subtract this value from the criteria. Even if there were no watershed sources of nitrogen, there would still be some nitrogen in the estuary due to the presence of nitrogen in Gulf of Maine waters. This concentration had to be estimated for each subestuary. Three variables were used for this calculation: The salinity in the subestuary, the salinity in the ocean, and the nitrogen concentration in the ocean. The ratio of the salinity in the subestuary to the salinity in the ocean is equal to the ratio of fresh water to ocean water in the subestuary. This ratio multiplied by the nitrogen concentration in the ocean water (0.2 mg/L, as derived in DES, 2009) was used to approximate the nitrogen concentration in the estuary if there were no watershed sources of nitrogen. This concentration was subtracted from the numeric criteria to determine the allowable increase in nitrogen concentration due to watershed sources.

For example, in the Lamprey River subestuary in 2003-2004, the salinity in the subestuary was 12 ppt, the ocean salinity was 31.6 ppt, and the nitrogen concentration in ocean water in the Gulf of Maine offshore of Portsmouth Harbor was 0.2 mg N/L. If there were no sources of nitrogen from the watershed, then the nitrogen concentration in the subestuary due to ocean water would be 0.076 mg N/L (0.2*12/31.6). Therefore, in order to meet the nitrogen criterion to prevent low dissolved oxygen (0.45 mg N/L), watershed sources could only increase nitrogen concentrations in the subestuary by 0.374 mg N/L.

The second step was to determine the watershed nitrogen loading threshold which would result in a steady state nitrogen concentration equal to the criteria. At steady state, the nitrogen loading rate that would produce a steady state concentration is the product of the concentration and the water flushing rate. The allowable increase in nitrogen concentration due to watershed sources was calculated as the difference between the criteria and the nitrogen concentration in the estuary associated with ocean water. This concentration was then multiplied by the water flushing rate to estimate the allowable watershed load. Finally, as a margin of safety, the watershed nitrogen load was reduced by 10 percent following the approach used by DES for recent total maximum daily load studies.

For example, in the Lamprey River subestuary in 2003-2004, to prevent low dissolved oxygen the allowable increase in nitrogen concentrations due to watershed loads was 0.374 mg N/L. The total water flushing rate was 561 cfs (15,880 L/s). Therefore, the watershed nitrogen loading threshold to prevent low dissolved oxygen in this subestuary was 185 tons/year (5,346 mg N/s).

This calculation was performed for each of the ten subestuaries to determine the watershed nitrogen loading threshold to prevent low dissolved oxygen in the subestuary.

2.3.2 Nitrogen Loading Threshold to Protect Eelgrass in the Subestuary

To determine the nitrogen load threshold to protect eelgrass in each subestuary, the method to calculate the threshold for preventing low dissolved oxygen was used but with the criterion to prevent eelgrass (0.3 mg N/L) substituted for the criterion to prevent low dissolved oxygen (0.45 mg N/L).

For example, in the Lamprey River subestuary in 2003-2004, the nitrogen concentration in the subestuary due to ocean water would be 0.076 mg N/L. Therefore, in order to meet the nitrogen criterion to protect eelgrass (0.30 mg N/L), watershed sources could only increase nitrogen concentrations in the subestuary by 0.224 mg N/L. The total water flushing rate was 561 cfs (15,880 L/s). Therefore, the watershed nitrogen loading threshold to protect eelgrass in this subestuary was 111 tons/year (3,202 mg N/s).

2.3.3 Nitrogen Loading Threshold to Protect Eelgrass in Downstream Subestuaries

The Great Bay, Little Bay, and Upper Piscataqua River subestuaries are downstream from the tidal river subestuaries. The nitrogen loading thresholds for the tidal river subestuaries need to support designated uses locally (i.e., in the subestuary) as well as in downstream areas. Therefore, in addition to having loading thresholds to prevent local effects, the tidal river subestuaries needed nitrogen loading thresholds to prevent effects on eelgrass in downstream areas.

For each of the tidal river subestuaries, a nitrogen loading threshold that should be supportive of downstream uses was estimated. This calculation involved several assumptions. The two most important assumptions were that: (1) Wastewater treatment plants in the Upper and Lower Piscataqua River would at least have an 8 mg/L total nitrogen permit limit; and (2) Nitrogen loads from all contributing watersheds would be reduced equally. Specifically, the methods for calculating the downstream protective load thresholds were:

1. The delivered nitrogen load to Great Bay, Little Bay, and the Upper Piscataqua River from wastewater discharges in the Upper and Lower Piscataqua River were calculated assuming their design flow and 8 mg/l effluent concentrations. A permit limit of 8 mg/l for total nitrogen in effluent and design flow is the least restrictive permitting option for these WWTFs. Therefore, this assumption was conservative in that contributions of nitrogen from these WWTFs will not be greater and may be lower. The wastewater discharges included in this calculation were Portsmouth, Kittery, Newington, Pease, and Dover. The Dover wastewater discharge was only relevant to the Upper Piscataqua River. The Portsmouth, Kittery, Newington, and Pease discharges contributed nitrogen to the Great Bay, Little Bay, and Upper Piscataqua River. Appendix A contains the methods for calculating the percent of nitrogen from each discharge that was delivered to Great Bay, Little Bay, and Upper Piscataqua River.
2. The delivered nitrogen loads from wastewater discharges in the Upper and Lower Piscataqua River were subtracted from the nitrogen loading threshold to protect eelgrass in the Great Bay, Little Bay, and Upper Piscataqua River. This difference represents the available allocation of nitrogen loads for upstream watersheds and shoreland areas. In essence, a conservative estimate of the delivered loads from the wastewater discharges in the Upper and Lower Piscataqua River was held in reserve and the remaining allocation was assigned to the upstream areas.
3. The relative contribution of nitrogen from each of the upstream watersheds and shoreland areas was calculated. The purpose of this calculation was to determine the percent of the existing nitrogen load attributable to each upstream watersheds and shoreland areas.
4. Calculate the downstream protective load for each watershed. For this calculation, the total nitrogen allocation for all upstream watersheds from Step 2 was multiplied by the relative contribution to existing nitrogen loads for each upland watershed and drainage area (Step 3). Implicit in this calculation is the

assumption that all of the contributing watersheds will have equal percent reductions in nitrogen loads.
5. For the Winnicut, Exeter, and Lamprey River watersheds, two different downstream protective load calculations were performed for Great Bay and Little Bay. For these watersheds, the lower of the two downstream protective loads was used.

2.3.4 Total Nitrogen Loading Thresholds for Downstream Areas

After calculating the load thresholds for each subestuary, all of the individual thresholds were combined to determine the total load threshold for Great Bay, Little Bay, and Upper Piscataqua River for three conditions. This calculation was needed to provide overall loading reduction numbers for the watershed. However, when setting waste load allocations for individual wastewater treatment facilities, the load thresholds for each subestuary will be more useful.

Three outcome conditions were chosen to combine the loading thresholds.

The first condition was protecting eelgrass in the Great Bay, Little Bay, and Upper Piscataqua River only. The calculated loading thresholds to protect eelgrass locally for each of these downstream subestuaries were used for this condition.

The second condition was protecting eelgrass in the Great Bay, Little Bay, and Upper Piscataqua River while also preventing low dissolved oxygen in the other subestuaries. In some subestuaries, the loading threshold to prevent low dissolved oxygen locally was less than the loading threshold to protect eelgrass in downstream areas. Therefore, for this condition, the total loading threshold for each of these downstream subestuaries was calculated by:

1. Start with the calculated loading thresholds to protect eelgrass locally for each of the downstream subestuaries (same values as for the first condition).
2. For each contributing watershed, if the loading threshold to prevent low dissolved oxygen locally was less than the loading threshold to protect eelgrass in downstream areas, calculate the difference between these two values.
3. Sum the differences calculated in Step 2 for all the contributing watersheds.
4. Subtract the sum of the differences from Step 3 from the calculated loading thresholds to protect eelgrass locally for each of the downstream subestuaries.

The third condition was protecting eelgrass in all areas. In most subestuaries, the loading threshold to protect eelgrass locally was less than the loading threshold to protect eelgrass in downstream areas. Therefore, for this condition, the total loading threshold for each of the downstream areas was calculated by:

1. Start with the calculated loading thresholds to protect eelgrass locally for each of the downstream subestuaries (same values as for the first condition).

2. For each contributing watershed, if the loading threshold to eelgrass locally was lower than the loading threshold to protect eelgrass in downstream areas, calculate the difference between these two values.
3. Sum the differences calculated in Step 2 for all the contributing watersheds.
4. Subtract the sum of the differences from Step 3 from the calculated loading thresholds to protect eelgrass locally for each of the downstream subestuaries.

These total loading thresholds were calculated for the Great Bay, Little Bay, and the Upper Piscataqua River. The total loading threshold for the whole system was calculated by summing the totals for Little Bay and the Upper Piscataqua River. The percent reduction in nitrogen loads needed to reach the thresholds was calculated using the watershed nitrogen loading values derived in Appendix A.

3 Results

3.1 Water Budgets for Subestuaries

The water budgets for each subestuary in 2003-2004, 2005-2006, and 2007-2008 are provided in Tables 11, 12, and 13, respectively. The majority of the fresh water flow to the subestuaries was from watersheds upstream of tidal dams. The other components of the fresh water budget were minor. Fresh water inputs to the Great Bay/Little Bay were similar to fresh water inputs to the Upper Piscataqua River. However, ocean water inputs to the Great Bay/Little Bay were more than 40% higher than to the Upper Piscataqua River. The finding is consistent with the particle tracking model results described in Appendix A, which show that more of the tidal flow into the estuary enters the Great Bay/Little Bay than the Upper Piscataqua River.

3.2 Nitrogen Loading Thresholds

The nitrogen loading thresholds for each of the tidal river subestuaries are shown on Table 14. This table contains the results for the three periods (2003-2004, 2005-2006, 2007-2008) as well as an overall average. These thresholds have been compared to measured nitrogen loads in Table 15 and on Figures 12 through 18. All of the tidal river subestuaries required average load reductions of 34 to 58% to protect eelgrass locally and 21 to 37% to protect eelgrass in downstream areas. Relative to the thresholds to prevent low dissolved oxygen, some of the subestuaries either met or were close to this target (Lamprey, Bellamy, Oyster, and Salmon Falls Rivers), while others would need significant reductions to meet this target (Exeter and Cocheco Rivers).

For the downstream areas of Great Bay, Little Bay, and the Upper Piscataqua River, the total loading thresholds associated with different water quality conditions are provided on Table 16 and on Figures 19 through 22. This table shows that, on average, the total load of nitrogen from watersheds needs to be reduced by 30% to protect eelgrass in downstream areas, by 31% to protect eelgrass in downstream areas and prevent low dissolved oxygen in the tidal river subestuaries, and by 45% to protect eelgrass in all areas (this load would also prevent low dissolved oxygen).

One important observation is that the nitrogen loading thresholds for preventing low dissolved oxygen in the tidal river subestuaries and protecting eelgrass in downstream areas are usually similar. Therefore, if nitrogen loads are reduced enough to protect eelgrass habitat in the downstream areas, episodes of low dissolved oxygen in the tidal rivers will also be eliminated.

4 References

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5 Tables

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Table 1: Watershed drainage areas and properties for modeled subestuaries

Watershed	Units	Winnicut River	Exeter River	Lamprey River	Oyster River	Bellamy River	Cocheco River	Salmon Falls River	Great Works River	Great Bay[1]	Little Bay[1]	Upper Piscataqua[1]
Drainage Area Above Dam	(sq.mi.)	14.16	106.90	211.90	19.85	27.26	175.28	235.00	86.69	0.00	0.00	0.00
Drainage Area Below Dam Including Tidal Waters	(sq.mi.)	4.64	19.77	1.87	11.17	6.51	9.77	7.88	0.00	22.15	6.33	12.81
Land Drainage Area Below Dam	(sq.mi.)	4.45	19.29	1.70	10.67	5.83	9.49	7.30	0.00	15.56	3.48	11.54
Surface Area of Assessment Zone	(sq.mi.)	0.19	0.48	0.17	0.50	0.68	0.28	0.57	0.00	6.59	2.85	1.27
Perimeter of Assessment Zone	(mi)	4.71	15.95	4.60	11.15	12.89	8.96	9.91	0.00	22.93	15.05	11.10
Perimeter Not Associated with Tidal Shoreline[2]	(ft)	2,400	1,400	1,600	1,700	2,100	600	900	0	6,700	6,500	4,300
Tidal Shoreline	(mi)	4.25	15.68	4.30	10.83	12.49	8.84	9.74	0.00	21.66	13.82	10.28

1. The values for Great Bay, Little Bay, and Upper Piscataqua do not include drainage areas or shoreline lengths that are included in contributing tributary watersheds. Contributing watersheds for the Great Bay are the Winnicut, Exeter, and Lamprey rivers. Contributing watersheds for Little Bay are Winnicut, Exeter, Lamprey, Oyster, and Bellamy rivers and the drainage area for Great Bay. Contributing watersheds for the Upper Piscataqua River are the Cocheco, Salmon Falls, and Great Works rivers.
2. The perimeter lengths not associated with tidal shoreline are water boundaries between assessment zones.
3. The head-of-tide dam on the Winnicut River was removed in 2009. The drainage areas in this table are relative to the head-of-tide monitoring station.

Table 2: Stream flow transposition factors for tributaries to the Great Bay Estuary

Head-of-Tide Monitoring Station	Watershed Area for Station (sq miles)	USGS Streamgage Number	Watershed Area for Streamgage (sq miles)	Flow Multipier for Transpositions	Comments
Lamprey River (05-LMP)	211.56	01073500	183	1.16	
Exeter River (09-EXT)	106.92	01073587	63.5	1.68	
Oyster River (05-OYS)	19.83	01073000	12.1	1.64	
Cocheco River (07-CCH)	175.23	01072800	85.7	2.04	
Salmon Falls River (05-SFR)	235.00	01073500		1.28	CFSM transposition with Lamprey gage
Bellamy River (05-BLM)	27.30	01072800		0.16	50% of flow from CFSM transposition with Cocheco gage
		01073000		1.13	50% of flow from CFSM transposition with Oyster gage
Winnicut River (02-WNC)	14.24	01073785	14.1	1.01	For 2002, use CFSM transposition with Oyster gage
Great Works River (02-GWR)	86.70	01072800		1.01	CFSM transposition with Cocheco gage

Table 3: Annual average stream flow measured at USGS gages (cfs)

Year	01072800		01073000		01073500		01073587		01073785	
	n	ave	n	ave	n	ave	n	ave	n	ave
2003	365	142.08	365	19.35	365	302.96	365	100.98	365	23.99
2004	366	136.92	366	18.45	366	292.67	366	106.17	366	23.75
2005	365	229.62	365	31.16	365	469.89	365	176.57	365	36.74
2006	365	240.14	365	34.23	365	536.52	365	202.21	365	51.69
2007	365	143.40	365	24.34	365	314.82	365	106.59	365	25.14
2008	366	250.65	366	38.31	366	492.50	366	197.74	366	41.65

Table 4: Annual average water withdrawals upstream of USGS gages (cfs)

Year		01072800		01073000		01073500		01073587		01073785
		ave		ave		ave		ave		ave
2003		***3.55***		0.34		0.51		0		1.52
2004		***3.55***		0.43		0.30		0		1.53
2005		***3.55***		0.42		***0.15***		0		1.62
2006		***3.55***		0.38		0.00		0		1.44
2007		***3.55***		0.33		0.03		0		1.45
2008		3.55		0.31		0.20		0		1.19

Note: Values in ***bold, red italics***. Assuming a constant withdrawal of 3.55 cfs upstream of gage 01072800 because yearly data do not exist. Using average of withdrawals in 2004 and 2006 to represent 2005 upstream of gage 01073500
The withdrawals upstream of gage 01072800 are: Rochester Reservoir.
The withdrawals upstream of gage 01073000 are: UNH Lee 5 Corners Well
The withdrawals upstream of gage 01073500 are: UNH Lamprey River withdrawal
The withdrawals upstream of gage 01073785 are: 9 wells run by Aquarion Water Company (water supply for Hampton)

Table 5: Corrected annual average stream flow at USGS gages (cfs)

Year	01072800		01073000		01073500		01073587		01073785	
	n	Ave	n	ave	n	ave	n	ave	n	ave
2003	365	145.63	365	19.69	365	303.47	365	100.9803	365	25.50
2004	366	140.47	366	18.88	366	292.97	366	106.1727	366	25.28
2005	365	233.17	365	31.58	365	470.04	365	176.5652	365	38.36
2006	365	243.70	365	34.61	365	536.52	365	202.211	365	53.13
2007	365	146.96	365	24.67	365	314.85	365	106.5863	365	26.59
2008	366	254.21	366	38.61	366	492.70	366	197.7369	366	42.84

Table 6: Predicted annual average stream flow at head-of-tide stations based on corrected annual average stream flow at USGS gages (cfs)

Year	Winnicut River at 02-WNC	Exeter River at 09-EXT	Lamprey River at 05-LMP	Oyster River at 05-OYS	Bellamy River at 05-BLM	Cocheco River at 07-CCH	Salmon Falls River at 05-SFR	Great Works River at 02-GWR
2003	25.75	170.04	350.83	32.26	45.42	297.77	389.71	147.33
2004	25.52	178.78	338.69	30.93	43.68	287.22	376.22	142.11
2005	38.73	297.31	543.39	51.74	72.77	476.76	603.61	235.89
2006	53.64	340.49	620.24	56.70	77.87	498.28	688.97	246.54
2007	26.85	179.47	363.98	40.42	51.25	300.48	404.31	148.67
2008	43.26	332.96	569.59	63.27	84.06	519.77	632.71	257.17

Table 7: Annual precipitation recorded at weather stations in the Great Bay Estuary watershed

Year	Greenland, NH	Rochester, NH	Eliot, ME	Sanford, ME	Average
	43.02 N, 70.83 W	43.30 N, 70.98 W	43.10 N, 70.77 W	43.45 N, 70.78 W	
2003	47.29	46.51	42.67	45.10	45.39
2004	46.13	48.97	43.58	47.19	46.47
2005	59.42	68.28	NA	72.02	66.57
2006	74.64	65.17	69.68	65.54	68.76
2007	51.39	51.60	55.77	NA	52.92
2008	67.81	70.33	65.08	67.88	67.78

Data Source: Climatological Data Annual Summaries for New England from the National Climatic Data Center
Note: These four stations had the most complete records of precipitation for the 2003-2008 period out of all weather stations in the Great Bay Estuary watershed.
NA: Incomplete data (as deemed by NCDC) for Eliot in 2005 and Sanford in 2007.

Table 8: Annual average water withdrawals for municipal water supplies which discharge outside of the watershed (cfs)

WATERSHED	WU_NAME	SD_NAME	LOCATION OF DISCHARGE (ESTUARY)	2002	2003	2004	2005	2006	2007	2008
Bellamy	DOVER WATER DEPARTMENT	BELLAMY RIVER INTAKE	Discharged to UPR estuary	0.207	***0.207***	***0.207***	***0.207***	***0.207***	***0.207***	***0.207***
		GRIFFIN WELL	Discharged to UPR estuary	0.498	0.357	0.457	0.343	0.458	0.403	0.242
		HUGHES WELL	Discharged to UPR estuary	0.152	0.128	0.127	0.098	0.284	0.289	0.210
		IRELAND WELL	Discharged to UPR estuary	0.818	0.869	0.844	0.816	0.696	0.530	0.470
	PORTSMOUTH WATER WORKS	BELLAMY RESERVOIR	Discharged to Portsmouth Harbor	***3.952***	***3.952***	***3.952***	***3.952***	***3.952***	***3.952***	3.952
Cocheco	DOVER WATER DEPARTMENT	CALDERWOOD WELL	Discharged to UPR estuary	0.783	0.768	0.820	0.967	0.852	0.836	0.588
		CAMPBELL WELL	Discharged to UPR estuary	0.604	0.714	0.817	0.895	0.757	0.555	0.559
		ISINGLASS RIVER INTAKE	Discharged to UPR estuary	1.574	2.234	2.207	2.223	1.331	0.325	***1.649***
		SMITH/CUMMINGS WELLS	Discharged to UPR estuary	0.641	0.525	0.509	0.651	0.598	0.712	0.582
Exeter	EXETER WATER DEPARTMENT	COMBINED SURFACE WATER	Discharge is to Squamscott River	1.250	1.194	1.168	1.212	1.190	1.574	***1.265***
		EXETER RESERVOIR	Discharge is to Squamscott River	***0.532***	***0.532***	***0.532***	***0.532***	***0.532***	0.365	0.700
		EXETER RIVER	Discharge is to Squamscott River	***1.382***	***1.382***	***1.382***	***1.382***	***1.382***	1.525	1.239
		LARY LANE WELL	Discharge is to Squamscott River	0.457	0.492	0.422	0.353	0.322	0.134	0.011
		SKINNER SPRINGS	Discharge is to Squamscott River	***0.073***	***0.073***	***0.073***	***0.073***	***0.073***	0.043	0.104
	NEWFIELDS WATER AND SEWER	BRW #6	Discharge is to Squamscott River	***0.024***	***0.024***	***0.024***	***0.024***	***0.024***	***0.024***	0.024
		GPW #1	Discharge is to Squamscott River	0.087	0.075	0.078	0.079	0.076	0.087	0.018
		GPW #2	Discharge is to Squamscott River	***0.003***	***0.003***	***0.003***	***0.003***	***0.003***	***0.003***	0.003
		GPW #4	Discharge is to Squamscott River	***0.016***	***0.016***	***0.016***	***0.016***	***0.016***	***0.016***	0.016
Great Bay	PORTSMOUTH WATER WORKS	PORTSMOUTH WELL #1	Discharged to Portsmouth Harbor	0.706	0.679	0.653	0.456	0.610	0.616	0.586
		SMITH WELL	Discharged to Portsmouth Harbor	0.378	0.259	0.290	0.425	0.193	0.016	0.185
Lamprey	NEWMARKET WATER WORKS	BENNETT WELL	Discharge is to Lamprey River	0.125	0.226	0.231	0.300	0.313	0.328	0.291
		FOLLETTS BROOK	Discharge is to Lamprey River	0.001	***0.001***	***0.001***	***0.001***	***0.001***	***0.001***	***0.001***
		LAMPREY RIVER	Discharge is to Lamprey River	0.969	0.450	0.378	***0.599***	***0.599***	***0.599***	***0.599***

WATERSHED	WU_NAME	SD_NAME	LOCATION OF DISCHARGE (ESTUARY)	2002	2003	2004	2005	2006	2007	2008
		PICASSIC RIVER	Discharge is to Lamprey River	0.590	***0.590***	***0.590***	***0.590***	***0.590***	***0.590***	***0.590***
		SEWALL WELL	Discharge is to Lamprey River	0.185	0.279	0.293	0.386	0.415	0.414	0.349
	UNIVERSITY OF NEW HAMPSHIRE	LAMPREY RIVER	Discharge is to Oyster River	0.258	0.511	0.299	***0.216***	0.001	0.026	0.201
Oyster	PORTSMOUTH WATER WORKS	MADBURY WELL #2	Discharged to Portsmouth Harbor	0.016	0.112	0.122	0.106	0.300	0.242	0.208
		MADBURY WELL #3	Discharged to Portsmouth Harbor	0.201	0.458	0.584	0.481	0.394	0.439	0.579
		MADBURY WELL #4	Discharged to Portsmouth Harbor	0.454	0.474	0.284	0.634	0.537	0.613	0.513
	UNIVERSITY OF NEW HAMPSHIRE	LEE 5 CORNERS WELL	Discharge is to Oyster River	0.468	0.343	0.432	0.421	0.377	0.335	0.308
		OYSTER RIVER	Discharge is to Oyster River	0.747	0.891	0.723	0.793	0.926	0.957	0.751
Winnicut	AQUARION WATER CO OF NH	BRW 13B NEXT TO COAKLEY	Discharge is to Hampton Harbor	***0.001***	***0.001***	***0.001***	***0.001***	0.001	0.000	0.000
		CAREY WELL #18	Discharge is to Hampton Harbor	0.174	0.197	0.213	0.113	0.102	0.121	0.116
		CAREY WELL #17	Discharge is to Hampton Harbor	0.111	0.105	0.102	0.101	0.081	0.087	0.075
		CAREY WELL #19	Discharge is to Hampton Harbor	0.188	0.131	0.126	0.115	0.099	0.096	0.109
		CRENSHAW WELL #10	Discharge is to Hampton Harbor	0.397	0.199	0.316	0.447	0.309	0.332	0.231
		PEABODY WELL #16	Discharge is to Hampton Harbor	0.311	0.361	0.343	0.399	0.389	0.352	0.305
		ROCKWELL WELL #13A	Discharge is to Hampton Harbor	0.241	0.187	0.002	0.001	0.000	0.000	0.000
		WELL #14 DALTON WELL	Discharge is to Hampton Harbor	0.058	0.089	0.076	0.037	0.087	0.075	0.075
		WINNICUTT WL #12 COAKLEY	Discharge is to Hampton Harbor	0.123	0.248	0.349	0.407	0.374	0.389	0.283
	PORTSMOUTH WATER WORKS	GREENLAND WELL #5	Discharge is to Portsmouth Harbor	0.932	0.986	1.005	1.048	0.908	0.684	0.624

Note: Values in ***bold, red italics*** were estimated to fill datagaps from missing values. The red values are the average of the available data between 2002 and 2008.

Table 9: Sum of annual average water withdrawals for municipal water supplies which discharge outside of the watershed (cfs)

Period	Winnicut	Exeter	Lamprey	Oyster	Bellamy	Cocheco	Salmon Falls	Great Bay	Little Bay	Upper Piscataqua
2003-2004	2.518	3.745	1.924	2.212	5.550	4.297	0	9.128	16.890	4.297
2005-2006	2.509	3.647	2.005	2.484	5.506	4.138	0	9.003	16.993	4.138
2007-2008	1.977	3.575	1.995	2.473	5.231	2.903	0	8.249	15.953	2.903

Note: Values calculated from Table 8.

Table 10: Summary of salinity data for subestuaries (ppt)

Assessment Zone	Period	Grab Samples		Datasonde Measurements			Station Maps (Selected Value)	
		N	Median	Station	N	Average	Value	Location
WINNICUT RIVER	2003-2004	24	13.3				13.0	GBCW-05
WINNICUT RIVER	2005-2006	66	13.0				10.0	GBCW-05
WINNICUT RIVER	2007-2008	46	19.2				13.0	GBCW-05
SQUAMSCOTT RIVER	2003-2004	151	4.3	GRBSQ	21,122	17.5	8.4	Stns from GRBCL to NH05-0214A
SQUAMSCOTT RIVER	2005-2006	94	2.1	GRBSQ	23,893	13.7	7.2	GRBCL, NH05-0214A
SQUAMSCOTT RIVER	2007-2008	79	5.0	GRBSQ	43,102	16.0	8.0	Note 1
LAMPREY RIVER	2003-2004	441	15.9	GRBLR	19,986	11.5	12.0	GRBLR (sonde)
LAMPREY RIVER	2005-2006	111	1.0	GRBLR	23,737	6.1	6.0	GRBLR (sonde)
LAMPREY RIVER	2007-2008	60	1.9	GRBLR	45,522	8.8	9.0	GRBLR (sonde)
OYSTER RIVER	2003-2004	101	22.0	GRBOR	21,635	19.5	20.0	GRBOR (sonde)
OYSTER RIVER	2005-2006	130	17.4	GRBOR	23,942	17.1	17.0	GRBOR (sonde)
OYSTER RIVER	2007-2008	131	21.0	GRBOR	44,612	19.6	20.0	GRBOR (sonde)
BELLAMY RIVER	2003-2004	109	22.2				22.0	GB33
BELLAMY RIVER	2005-2006	187	19.0				17.0	GB33
BELLAMY RIVER	2007-2008	262	21.3				20.0	GB33
COCHECO RIVER	2003-2004	99	4.0				9.0	Between GBCW-09 and NH05-0260A

Assessment Zone	Period	Grab Samples		Datasonde Measurements			Station Maps (Selected Value)	
		N	Median	Station	N	Average	Value	Location
COCHECO RIVER	2005-2006	85	2.0				5.0	Between GBCW-09 and NH05-0260A
COCHECO RIVER	2007-2008	66	5.0				9.0	Between GBCW-09 and NH-0058A
SALMON FALLS RIVER	2003-2004	33	3.0	GRBSF	9,211	16.4	10.0	NH-0062A, NH05-0263A, ME03-0272A
SALMON FALLS RIVER	2005-2006	10	6.0	GRBSF	8,193	16.4	8.5	NH05-0263A, ME03-0272A
SALMON FALLS RIVER	2007-2008	4	10.3	GRBSF	4,176	11.9	10.0	Note 2
GREAT BAY	2003-2004	250	22.0	GRBGB	19,477	23.5	23.5	GRBGB (sonde)
GREAT BAY	2005-2006	388	17.0	GRBGB	23,951	19.8	20.0	GRBGB (sonde)
GREAT BAY	2007-2008	451	19.9	GRBGB	46,261	21.7	22.0	GRBGB (sonde)
LITTLE BAY	2003-2004	410	25.0				25.0	GB17
LITTLE BAY	2005-2006	472	21.1				21.5	GB17
LITTLE BAY	2007-2008	504	22.7				23.0	GB17
UPPER PISCATAQUA RIVER	2003-2004	187	16.9				20.0	GBCW-10
UPPER PISCATAQUA RIVER	2005-2006	127	15.0				15.5	GBCW-10
UPPER PISCATAQUA RIVER	2007-2008	150	17.0				20.0	Note 3

Notes

1. There were limited data in the Squamscott River in 2007-2008. Average salinity in the study area between stations NH04-0214A and GRBCL was estimated using ratios of the average salinity measured by the datasonde at GRBSQ. In 2003-2004, the average salinities at GRBSQ and in the study area were 17.5 and 8.4 ppt, respectively. In 2005-2006, the average salinities at GRBSQ and in the study area were 13.7 and 7.2 ppt, respectively. In 2007-2008, the average salinity at GRBSQ was 16.0 ppt. The ratios from 2003-2004 and 2005-2006 would predict average salinities in the study area of 7.7 and 8.4 ppt, respectively. Therefore, 8.0 ppt was selected to represent the average salinity in the study area in 2007-2008.
2. Salinity data were only available at station NH-0062A in 2007. The average salinity in 2007 at this station was 14.7 ppt. Another station in the subestuary, GRBSF (sonde), was monitored in 2007 and 2008. This station recorded average salinities of 19.0 and 4.8 ppt in 2007 and 2008, respectively. The data from GRBSF indicate that the salinity in 2008 at NH-0062A would have been lower than the value recorded in 2007. Therefore, 10 ppt was chosen as the average salinity for the Salmon Falls River in 2007-2008. This value matches the average salinity for this subestuary in 2003-2004, which is consistent with the pattern observed in other subestuaries.
3. Salinity data were only available at station GBCW-10 in 2007. The average salinity in 2007 at this station was 22.2 ppt. Another station in the subestuary, NH-0057A, was monitored in 2007 and 2008. This station recorded average salinities of 18.8 and 12.7 ppt in 2007 and 2008, respectively. The data from NH-0057A indicate that the salinity in 2008 at GBCW-10 would have been lower than the value recorded in 2007. Therefore, 20 ppt was chosen as the average salinity for the Upper Piscataqua River in 2007-2008. This value matches the average salinity for this subestuary in 2003-2004, which is consistent with the pattern observed in other subestuaries.

Table 11: Water budgets for subestuaries in 2003-2004

Source	Units	Winnicut	Exeter	Lamprey	Oyster	Bellamy	Cocheco	Salmon Falls	Great Bay	Little Bay	Upper Piscataqua
Q from watershed above dam	(cfs)	25.63	174.41	344.76	31.60	44.55	292.49	527.69	544.80	620.94	820.18
Q from watershed below dam	(cfs)	8.05	31.47	2.77	16.98	9.52	15.84	11.98	67.08	99.61	46.76
Q direct precipitation to estuary surface	(cfs)	0.59	1.46	0.52	1.53	2.08	0.84	1.74	22.62	34.92	6.45
Q effluent below dam	(cfs)	0.00	2.85	1.04	1.47	0.00	0.00	0.51	3.88	5.36	4.90
Q groundwater along tidal shoreline	(cfs)	0.64	2.35	0.64	1.62	1.87	1.33	1.46	6.88	12.45	4.33
Q net loss/gain from water withdrawals	(cfs)	-2.52	-3.75	-1.92	-2.21	-5.55	-4.30	0.00	-9.13	-16.89	-4.30
Q subtotal - freshwater	(cfs)	32.39	208.79	347.80	51.00	52.46	306.20	543.37	636.15	756.39	878.32
Q from ocean	(cfs)	22.64	75.60	212.94	87.93	120.23	121.94	251.56	1845.61	2865.12	1514.34
Q total	(cfs)	55.03	284.39	560.74	138.93	172.69	428.14	794.93	2481.75	3621.51	2392.65
Q total	(L/s)	1,559	8,054	15,880	3,934	4,891	12,125	22,513	70,283	102,561	67,760

“Q” = Average Flow

Table 12: Water budgets for subestuaries in 2005-2006

		Winnicut	Exeter	Lamprey	Oyster	Bellamy	Cocheco	Salmon Falls	Great Bay	Little Bay	Upper Piscataqua
Q from watershed above dam	(cfs)	46.19	318.90	581.82	54.22	75.32	487.52	887.50	946.90	1076.45	1375.02
Q from watershed below dam	(cfs)	14.51	57.54	4.67	29.14	16.09	26.40	20.15	116.59	172.68	78.40
Q direct precipitation to estuary surface	(cfs)	0.87	2.15	0.76	2.26	3.06	1.24	2.56	33.33	51.44	9.50
Q effluent below dam	(cfs)	0.00	3.58	1.08	1.71	0.00	0.00	0.63	4.66	6.38	5.80
Q groundwater along tidal shoreline	(cfs)	0.64	2.35	0.64	1.62	1.87	1.33	1.46	6.88	12.45	4.33
Q net loss/gain from water withdrawals	(cfs)	-2.51	-3.65	-2.00	-2.48	-5.51	-4.14	0.00	-9.00	-16.99	-4.14
Q subtotal - freshwater	(cfs)	59.69	380.88	586.97	86.48	90.84	512.35	912.31	1099.37	1302.40	1468.91
Q from ocean	(cfs)	27.63	112.39	137.57	100.70	105.77	96.31	335.70	1895.46	2772.45	1414.17
Q total	(cfs)	87.32	493.27	724.54	187.18	196.61	608.65	1248.00	2994.83	4074.85	2883.08
Q total	(L/s)	2,473	13,969	20,519	5,301	5,568	17,237	35,343	84,814	115,400	81,649

"Q" = Average Flow

Table 13: Water budgets for subestuaries in 2007-2008

		Winnicut	Exeter	Lamprey	Oyster	Bellamy	Cocheco	Salmon Falls	Great Bay	Little Bay	Upper Piscataqua
Q from watershed above dam	(cfs)	35.05	256.22	466.79	51.85	67.65	410.12	721.43	758.06	877.55	1131.55
Q from watershed below dam	(cfs)	11.01	46.23	3.75	27.87	14.45	22.21	16.38	93.34	140.78	64.52
Q direct precipitation to estuary surface	(cfs)	0.77	1.92	0.68	2.01	2.73	1.11	2.28	29.72	45.88	8.47
Q effluent below dam	(cfs)	0.00	2.87	0.97	1.52	0.00	0.00	0.56	3.84	5.36	5.18
Q groundwater along tidal shoreline	(cfs)	0.64	2.35	0.64	1.62	1.87	1.33	1.46	6.88	12.45	4.33
Q net loss/gain from water withdrawals	(cfs)	-1.98	-3.58	-1.99	-2.47	-5.23	-2.90	0.00	-8.25	-15.95	-2.90
Q subtotal - freshwater	(cfs)	45.49	306.01	470.83	82.40	81.48	431.86	742.12	883.60	1066.07	1211.15
Q from ocean	(cfs)	31.80	103.73	187.50	142.07	140.48	171.98	343.58	2024.91	2851.12	2088.19
Q total	(cfs)	77.29	409.75	658.33	224.46	221.96	603.84	1085.70	2908.51	3917.18	3299.34
Q total	(L/s)	2,189	11,604	18,644	6,357	6,286	17,101	30,747	82,369	110,935	93,437

“Q” = Average Flow

Table 14: Predicted nitrogen loading thresholds to comply with numeric nutrient criteria (tons of nitrogen per year)

		Winnicut	Exeter	Lamprey	Oyster	Bellamy	Cocheco	Salmon Falls	Great Bay	Little Bay	Upper Piscataqua
2003-2004[1]	Prevent low DO locally	18	100	185	40	47	149	272	661	934	684
	Protect eelgrass locally	11	62	111	21	25	92	166	332	454	367
	Protect eelgrass downstream[2]	20	118	163	43	32	142	158	NA	NA	NA
2005-2006[1]	Prevent low DO locally	30	176	264	57	60	225	437	856	1,131	897
	Protect eelgrass locally	18	111	168	32	33	144	272	459	591	515
	Protect eelgrass downstream[2]	29	181	212	56	43	209	232	NA	NA	NA
2007-2008[1]	Prevent low DO locally	25	145	229	64	63	210	371	799	1,054	943
	Protect eelgrass locally	15	90	141	34	34	130	227	413	535	506
	Protect eelgrass downstream[2]	22	186	172	44	38	180	253	NA	NA	NA
Average	Prevent low DO locally	24	140	226	54	57	195	360	772	1,040	842
	Protect eelgrass locally	15	88	140	29	31	122	222	402	526	462
	Protect eelgrass downstream[2]	24	162	182	48	38	177	214	NA	NA	NA

Note 1: Total precipitation in 2003-2004, 2005-2006, and 2007-2008 was 43.7, 67.9, and 51.4 inches, respectively.
Note 2: Downstream protective values are the allowable nitrogen loads from this watershed that would support eelgrass in Great Bay, Little Bay, and the Upper Piscataqua River. These values were calculated by assuming downstream WWTFs (Dover, Portsmouth, Kittery, Pease, and Newington) were permitted at 8 mg/L and design flow and assuming an equal percent reduction across all contributing watersheds.
Note 3: Loading thresholds to protect eelgrass downstream were not calculated for the Great Bay, Little Bay, and Upper Piscataqua River because these subestuaries are the downstream areas.

Table 15: Measured nitrogen loads, nitrogen loading thresholds, and percent reductions needed for subestuaries

		Winnicut		Exeter		Lamprey		Oyster		Bellamy		Cocheco		Salmon Falls	
Period	Description	(tons/yr)	(%)	(tons/yr)	(%)	(tons/yr)	(%)	(tons/yr)	(%)	(tons/yr)	(%)	(tons/yr)	(%)	(tons/yr)	(%)
2003-2004	Measured nitrogen load	25		147		204		50		37		265		295	
	Threshold to prevent low DO locally	18	29%	100	32%	185	9%	40	21%	47	-27%	149	44%	272	8%
	Threshold to protect eelgrass locally	11	58%	62	58%	111	46%	21	58%	25	34%	92	65%	166	44%
	Threshold to protect eelgrass downstream	20	20%	118	20%	163	20%	43	15%	32	15%	142	47%	158	47%
2005-2006	Measured nitrogen load	40		252		295		77		60		337		374	
	Threshold to prevent low DO locally	30	26%	176	30%	264	11%	57	26%	60	0%	225	33%	437	-17%
	Threshold to protect eelgrass locally	18	55%	111	56%	168	43%	32	58%	33	44%	144	57%	272	27%
	Threshold to protect eelgrass downstream	29	28%	181	28%	212	28%	56	27%	43	27%	209	38%	232	38%
2007-2008	Measured nitrogen load	28		235		217		54		47		241		339	
	Threshold to prevent low DO locally	25	9%	145	38%	229	-6%	64	-19%	63	-36%	210	13%	371	-10%
	Threshold to protect eelgrass locally	15	46%	90	62%	141	35%	34	36%	34	27%	130	46%	227	33%
	Threshold to protect eelgrass downstream	22	21%	186	21%	172	21%	44	18%	38	18%	180	25%	253	25%
Average	Measured nitrogen load	31		212		239		60		48		281		336	
	Threshold to prevent low DO locally	24	21%	140	34%	226	5%	54	11%	57	-19%	195	31%	360	-7%
	Threshold to protect eelgrass locally	15	53%	88	58%	140	41%	29	52%	31	36%	122	57%	222	34%
	Threshold to protect eelgrass downstream	24	24%	162	24%	182	24%	48	21%	38	21%	177	37%	214	36%

Note 1: The percent column for each subestuary is the percent that the measured nitrogen load needs to be reduced to match the nitrogen loading threshold.

Table 16: Measured nitrogen loads, cumulative nitrogen loading thresholds for different conditions, and percent reductions needed for the Great Bay, Little Bay, and the Upper Piscataqua River

		Great Bay		Little Bay		Upper Piscataqua		Total[2]	
Period	Description	(tons/yr)	(%)	(tons/yr)	(%)	(tons/yr)	(%)	(tons/yr)	(%)
2003-2004	Measured nitrogen load	415		531		674		1206	
	Threshold to protect eelgrass in downstream areas only[3]	332	20%	454	15%	367	46%	821	32%
	Threshold to protect eelgrass in downstream areas and prevent low DO in rivers[3]	312	25%	431	19%	367	46%	797	34%
	Threshold to protect eelgrass in all areas	214	48%	307	42%	317	53%	624	48%
2005-2006	Measured nitrogen load	640		812		850		1662	
	Threshold to protect eelgrass in downstream areas only	459	28%	591	27%	515	39%	1105	34%
	Threshold to protect eelgrass in downstream areas and prevent low DO in rivers	454	29%	586	28%	515	39%	1101	34%
	Threshold to protect eelgrass in all areas	334	48%	432	47%	450	47%	881	47%
2007-2008	Measured nitrogen load	522		654		702		1355	
	Threshold to protect eelgrass in downstream areas only	413	21%	535	18%	506	28%	1041	23%
	Threshold to protect eelgrass in downstream areas and prevent low DO in rivers	372	29%	493	25%	506	28%	999	26%
	Threshold to protect eelgrass in all areas	280	46%	388	41%	429	39%	817	40%
Average	Measured nitrogen load	525		666		742		1408	
	Threshold to protect eelgrass in downstream areas only	402	24%	526	21%	462	38%	989	30%
	Threshold to protect eelgrass in downstream areas and prevent low DO in rivers	379	28%	503	24%	462	38%	966	31%
	Threshold to protect eelgrass in all areas	276	47%	376	44%	399	46%	774	45%

Note 1: The percent column for each subestuary is the percent that the measured nitrogen load needs to be reduced to match the nitrogen loading threshold.
Note 2: Total is the sum of the loads or thresholds for Little Bay and Upper Piscataqua because the Great Bay watershed is a subset of the Little Bay watershed.
Note 3: See Section 2.3.4 for the methods for calculating these totals.

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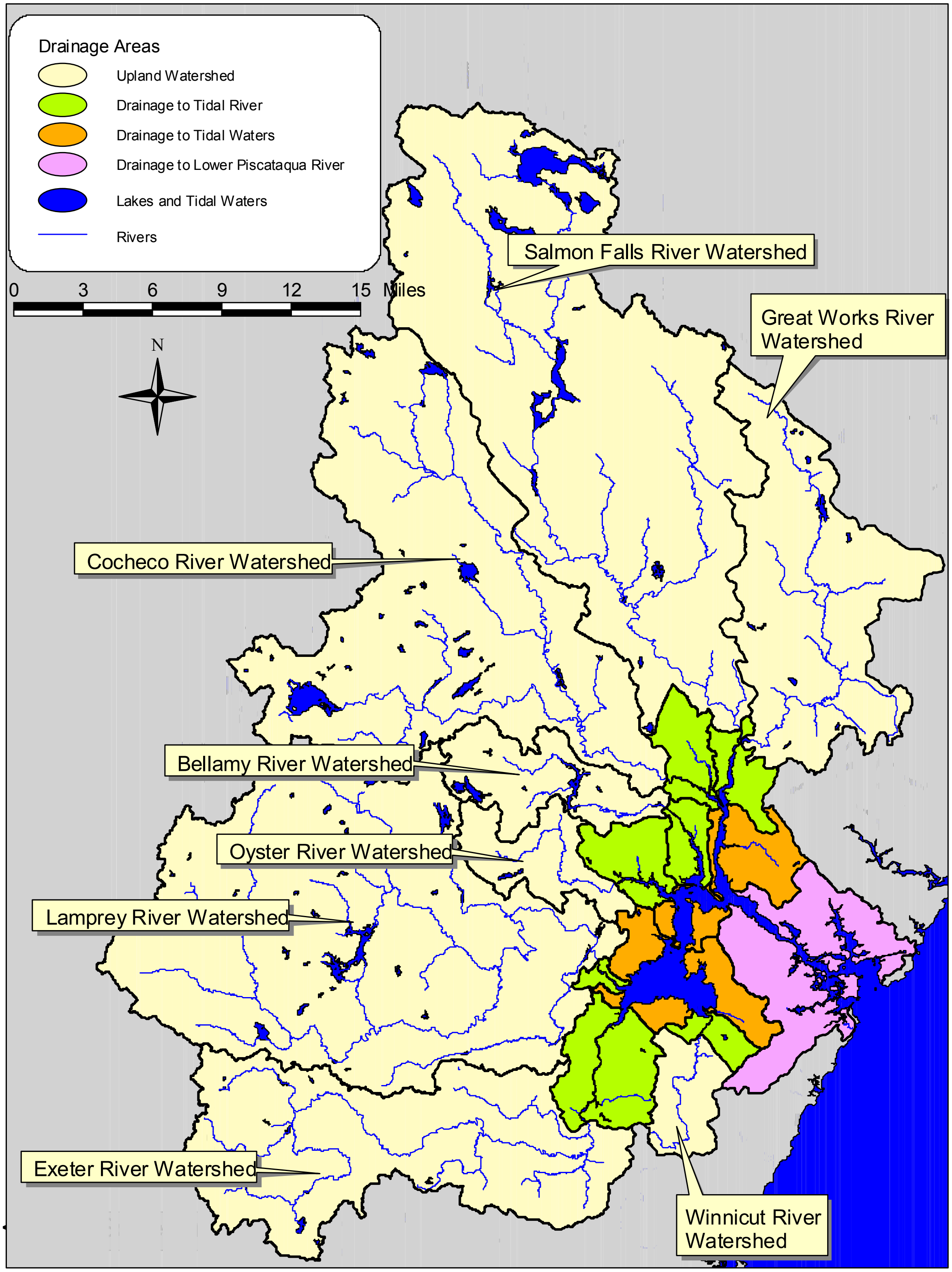
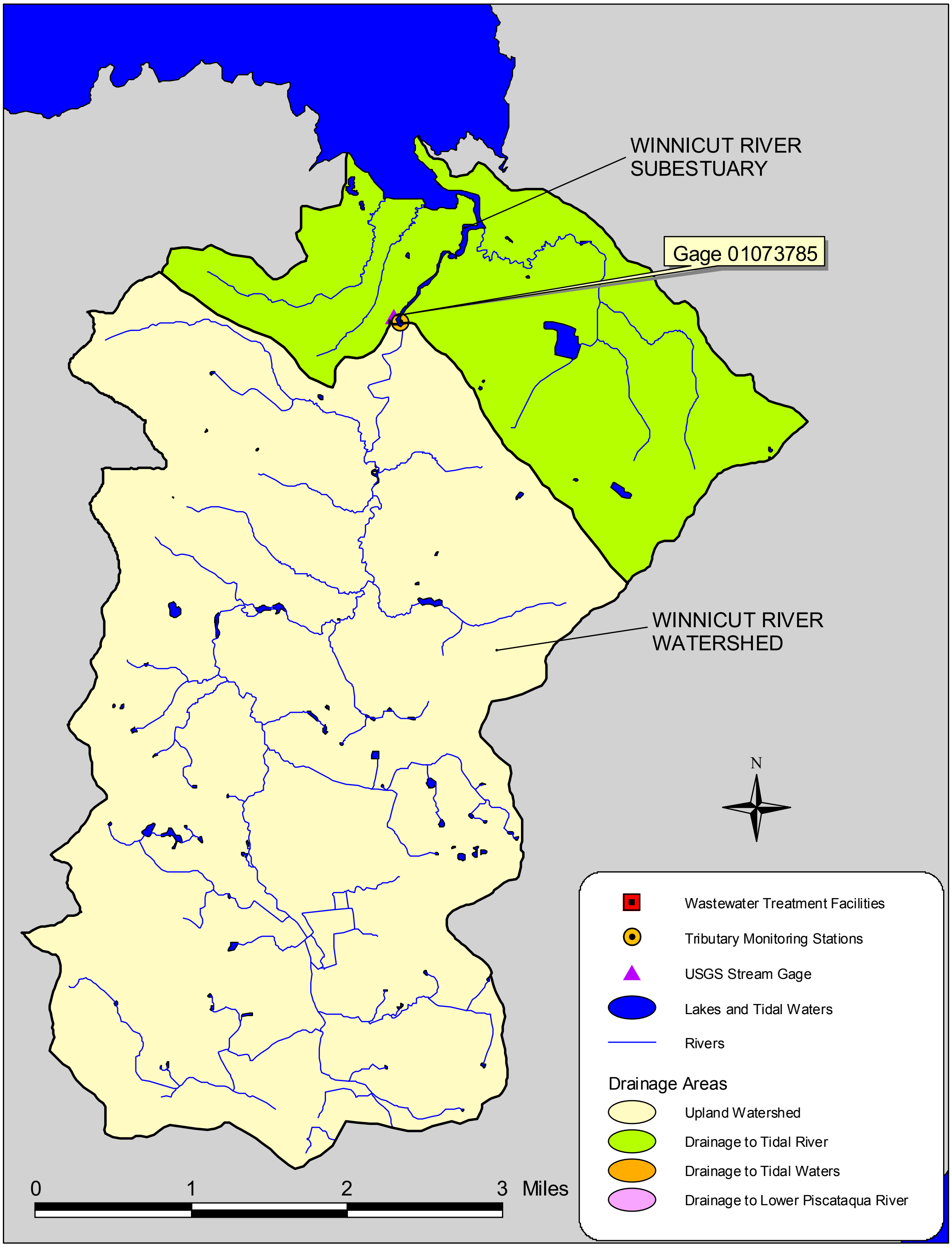


Figure 2: Watershed for the Winnicut River subestuary



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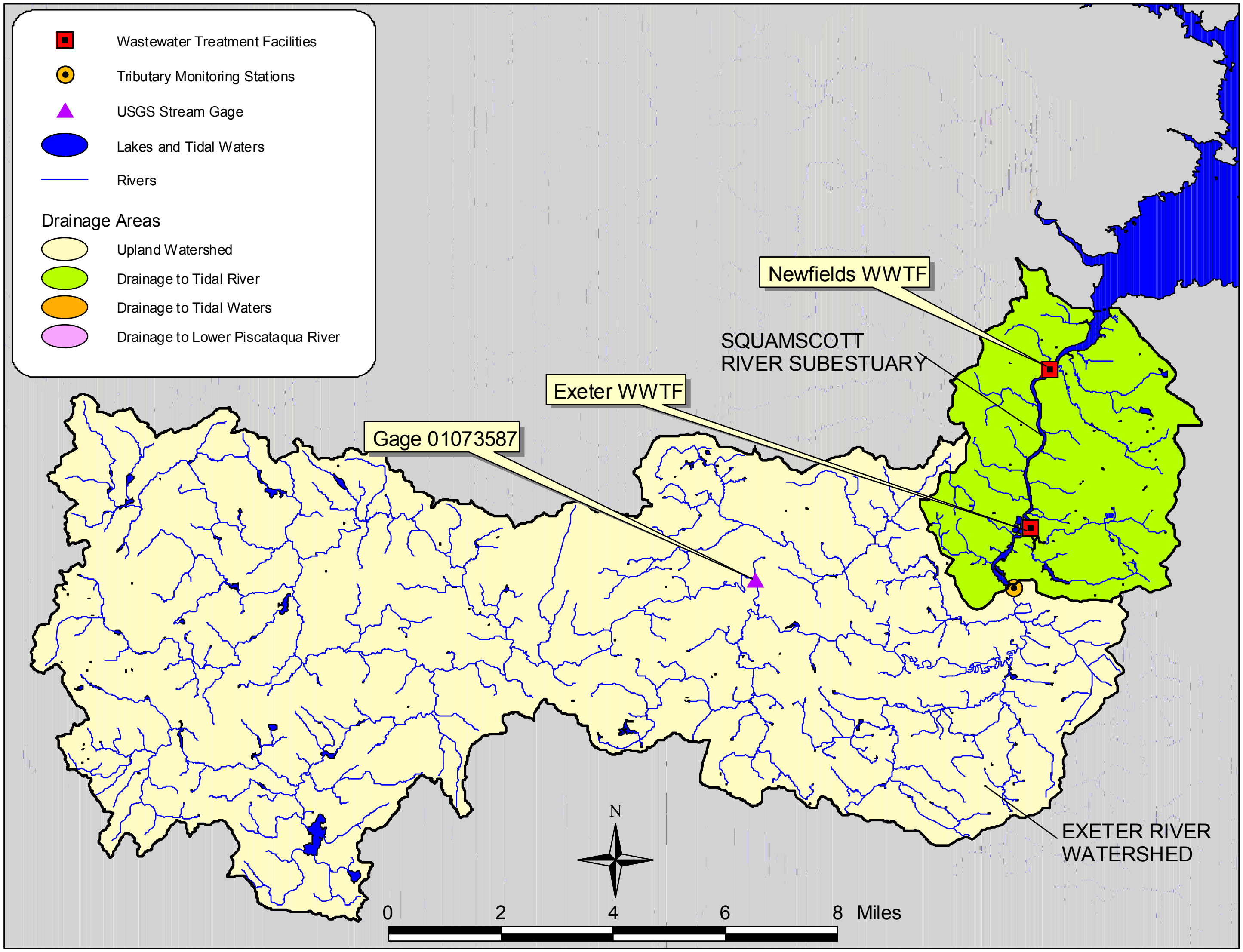
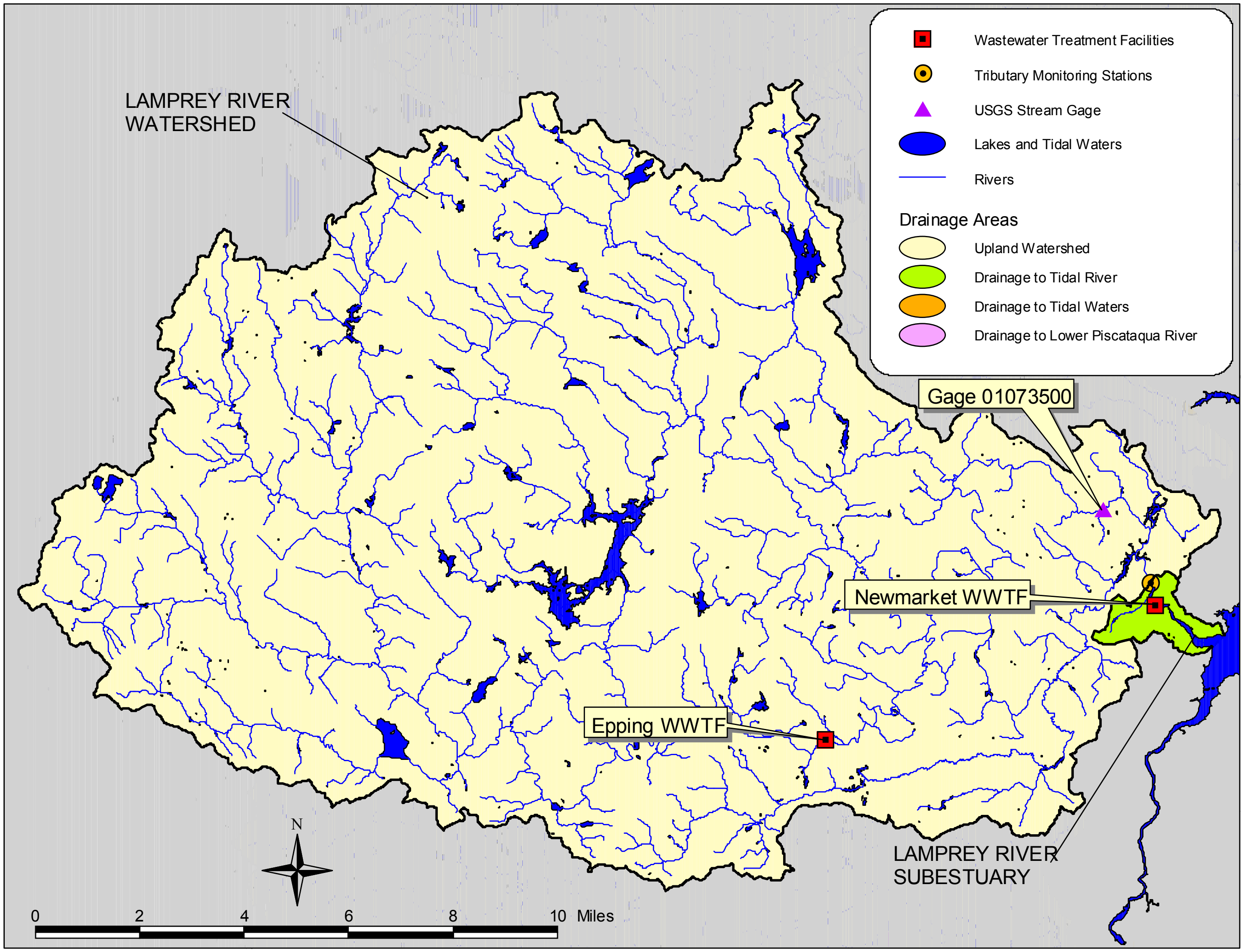


Figure 4: Watershed for the Lamprey River subestuary



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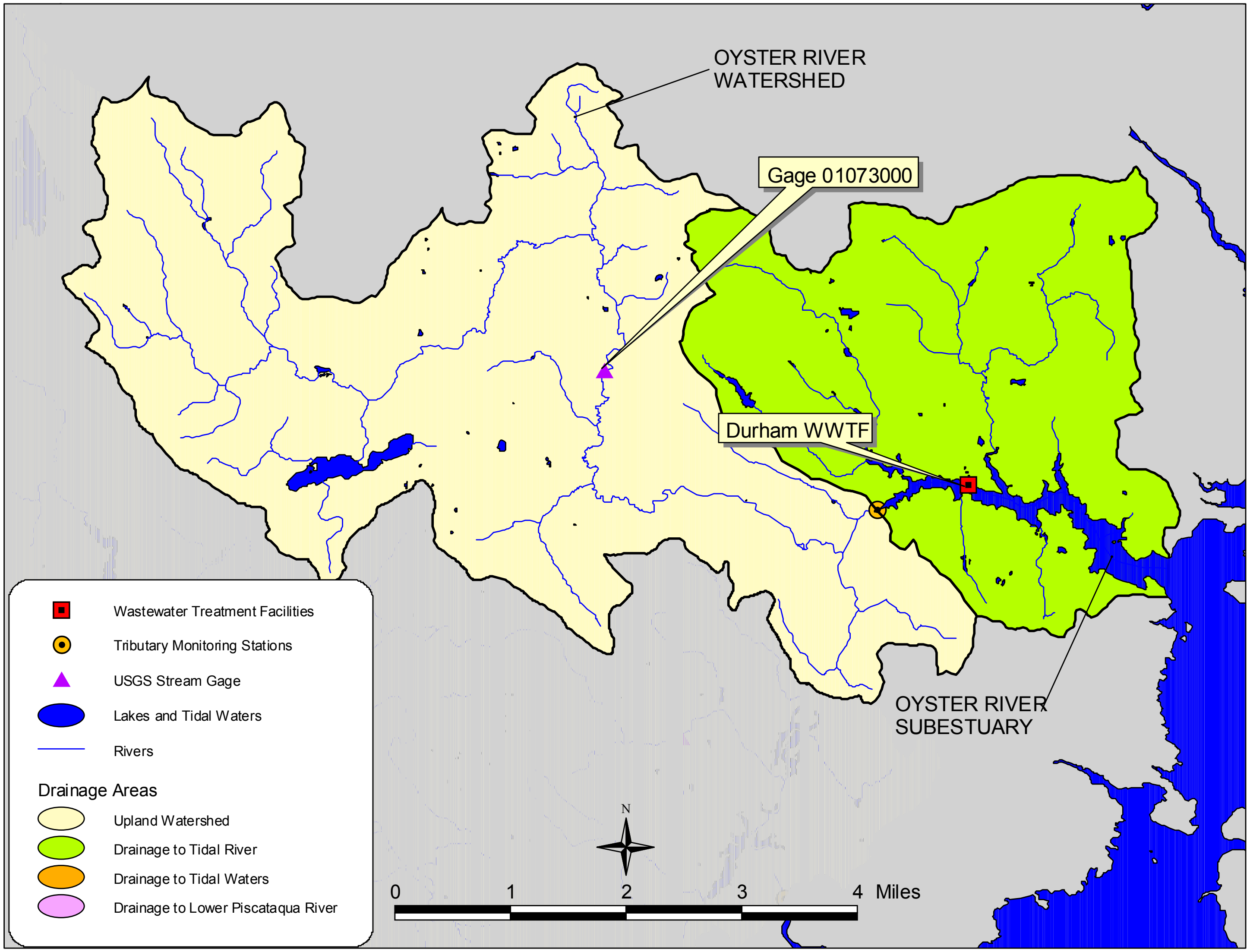

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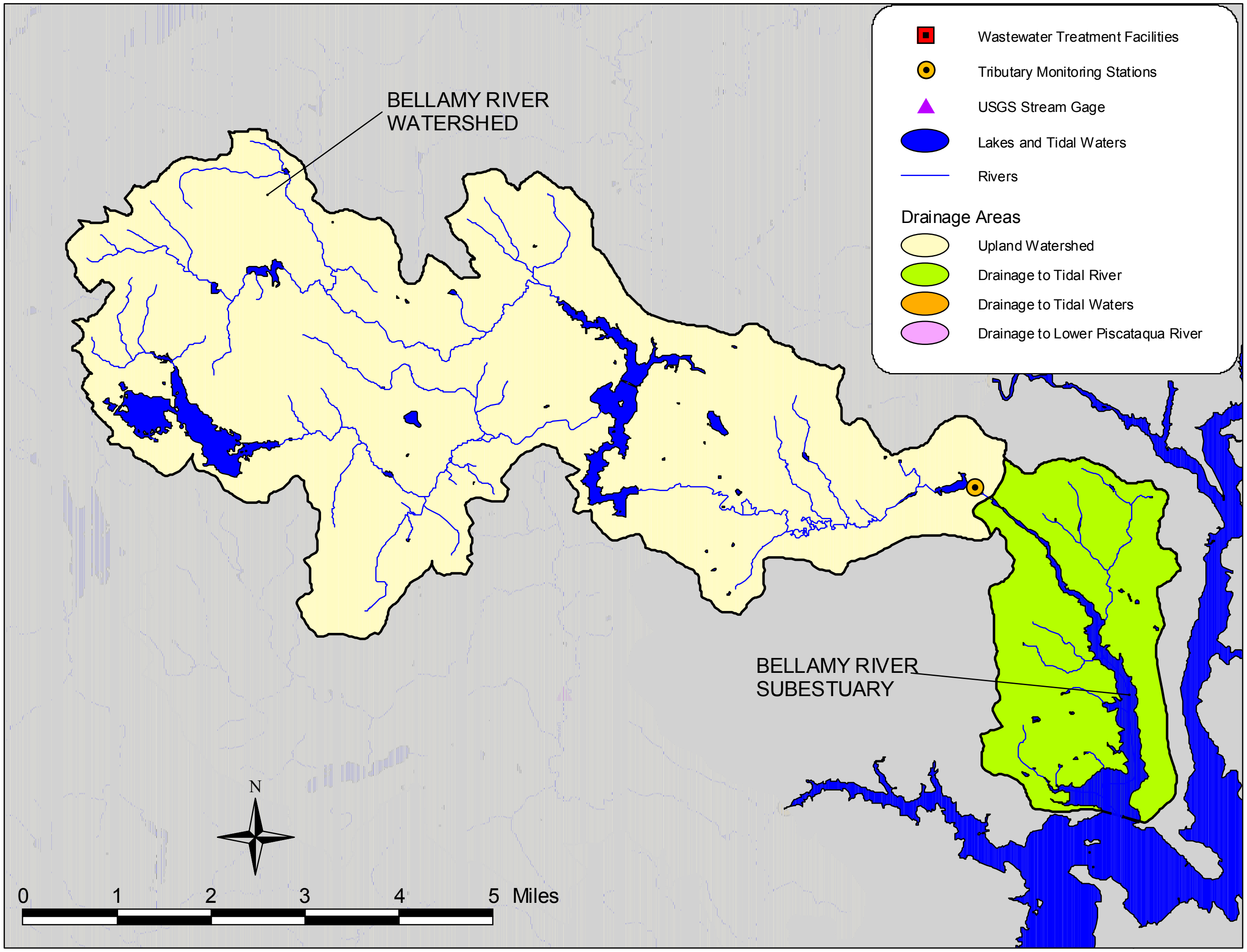

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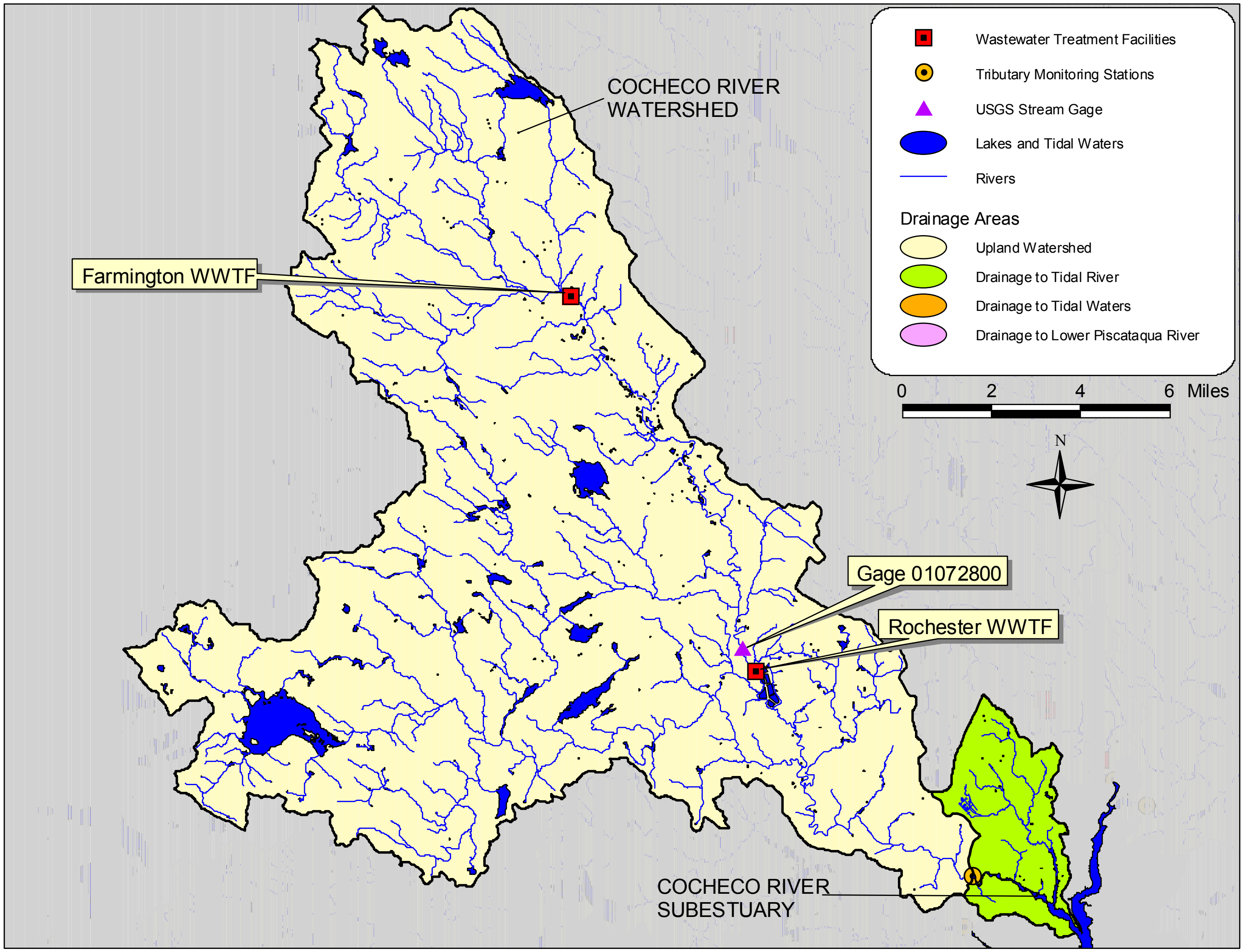
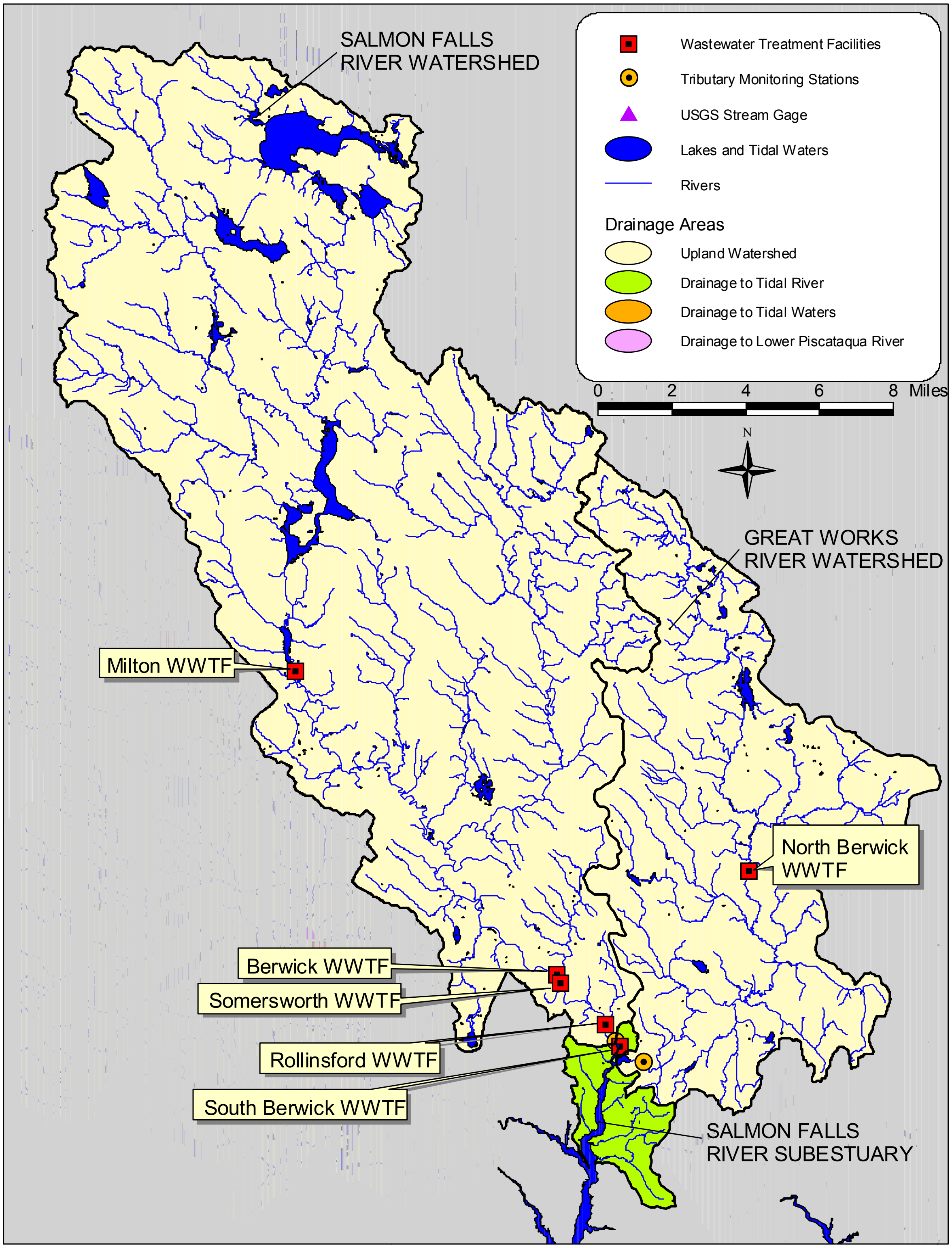


Figure 8: Watershed for the Salmon Falls River subestuary



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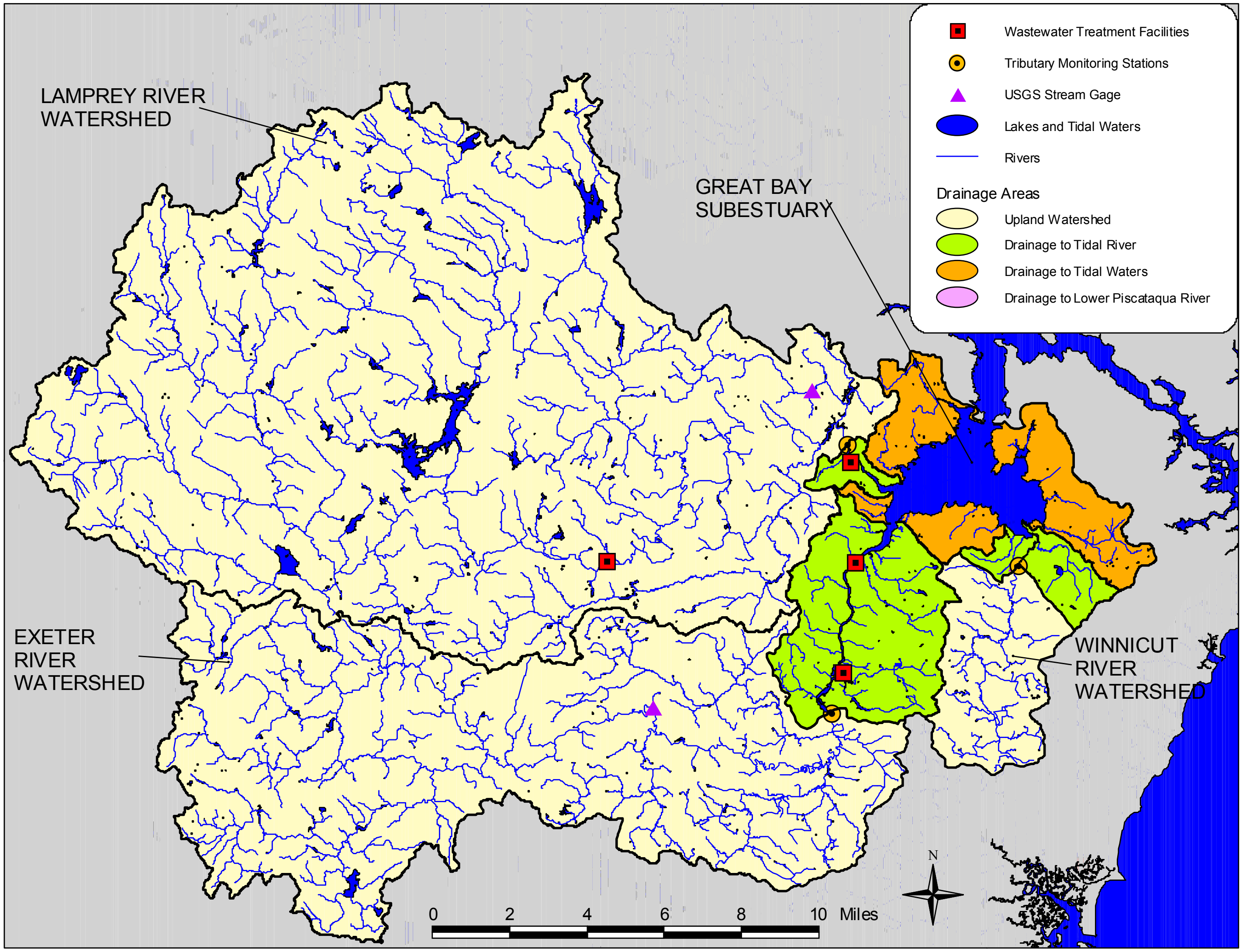
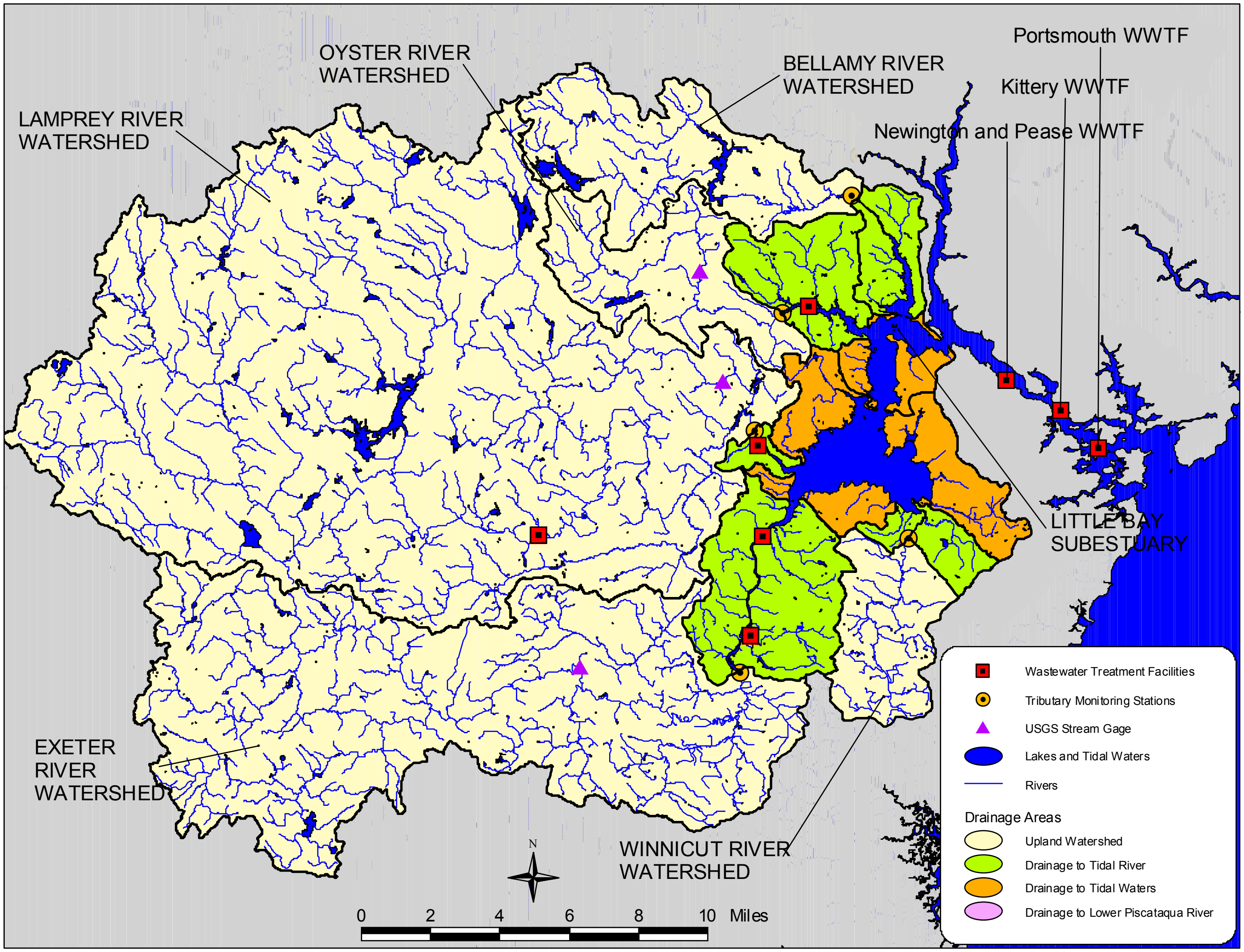


Figure 10: Watershed for the Little Bay subestuary



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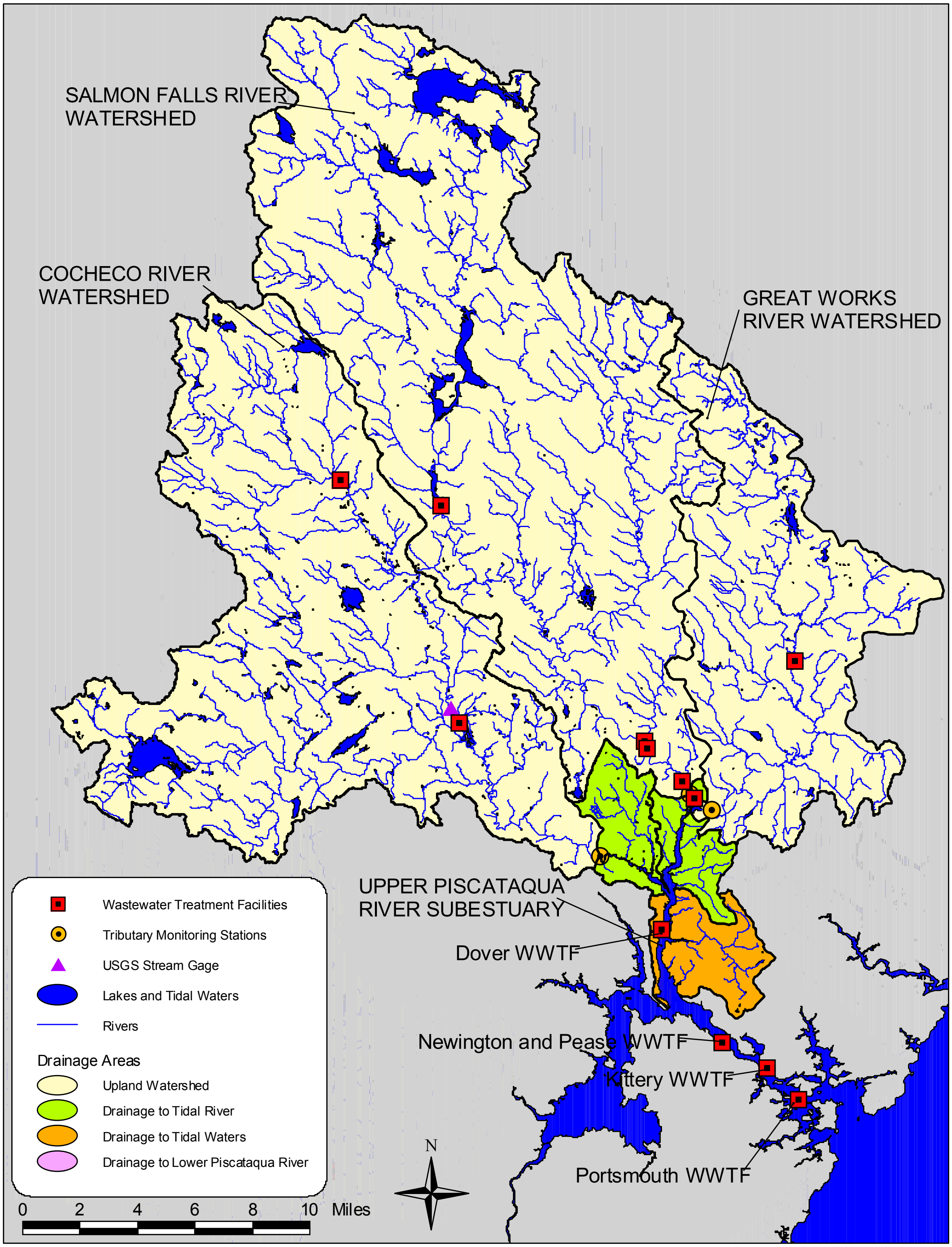


Figure 12: Measured nitrogen loads and load thresholds for the Winnicut River subestuary

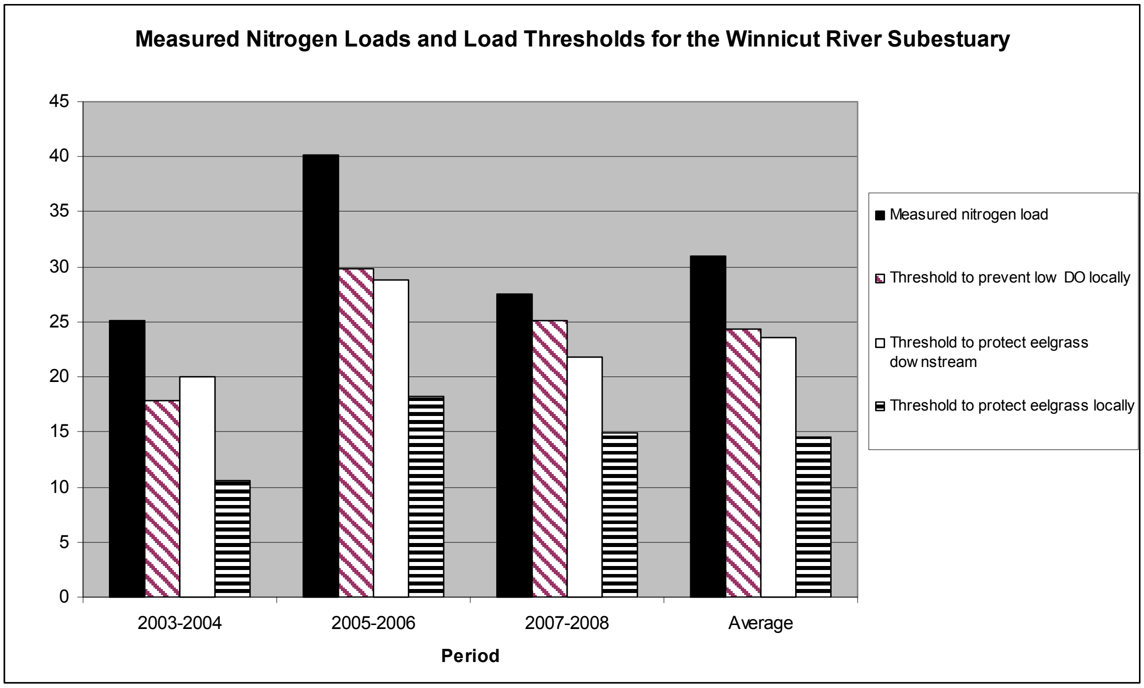
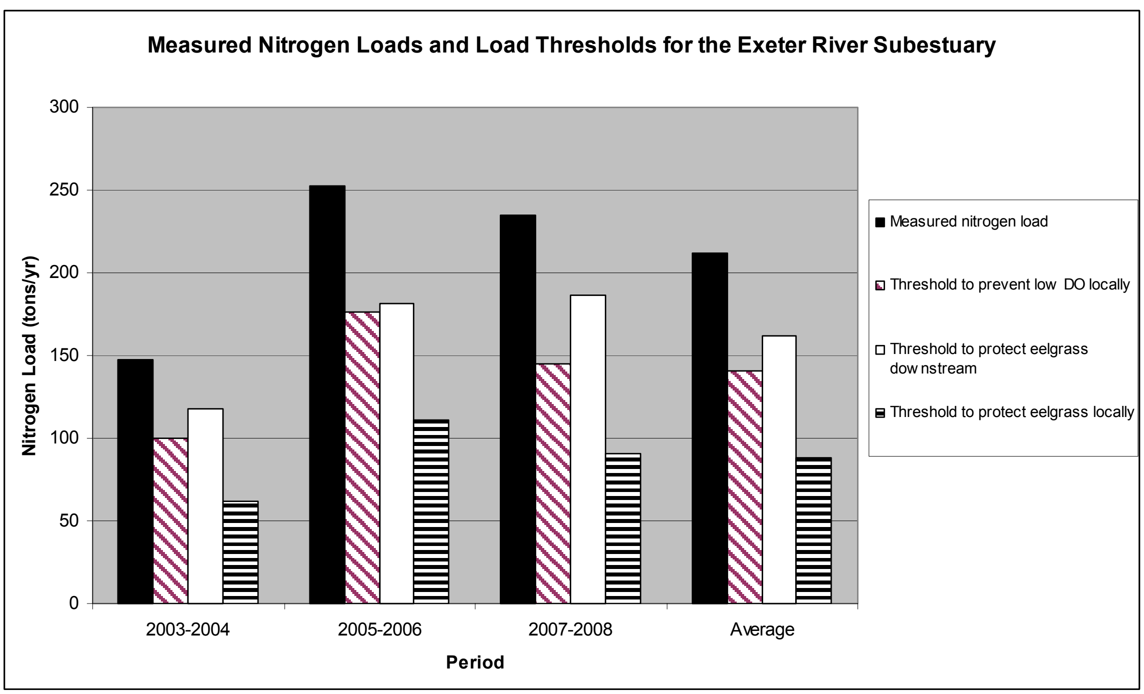


Figure 13: Measured nitrogen loads and load thresholds for the Exeter River subestuary



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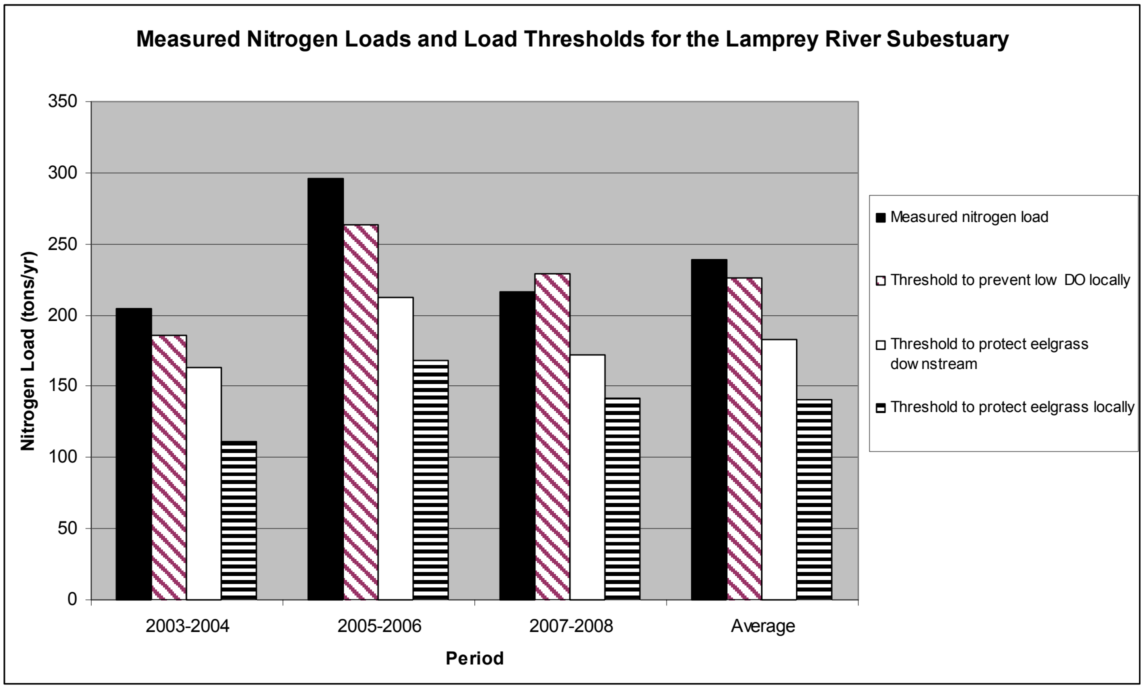


Figure 15: Measured nitrogen loads and load thresholds for the Oyster River subestuary

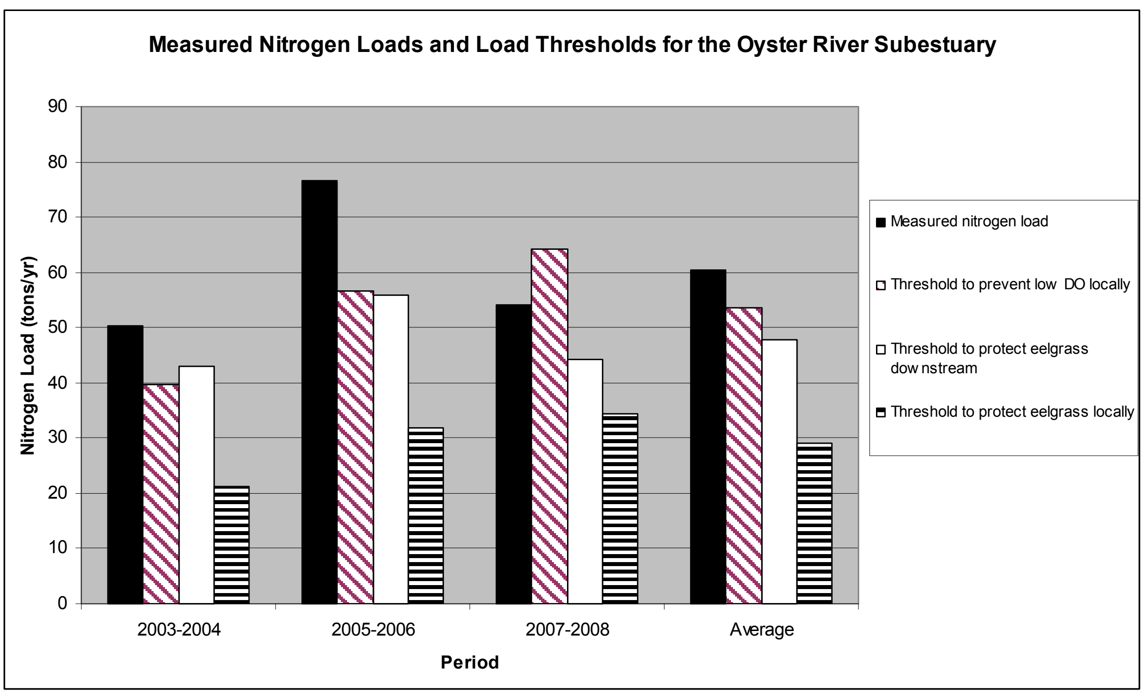


Figure 16: Measured nitrogen loads and load thresholds for the Bellamy River subestuary

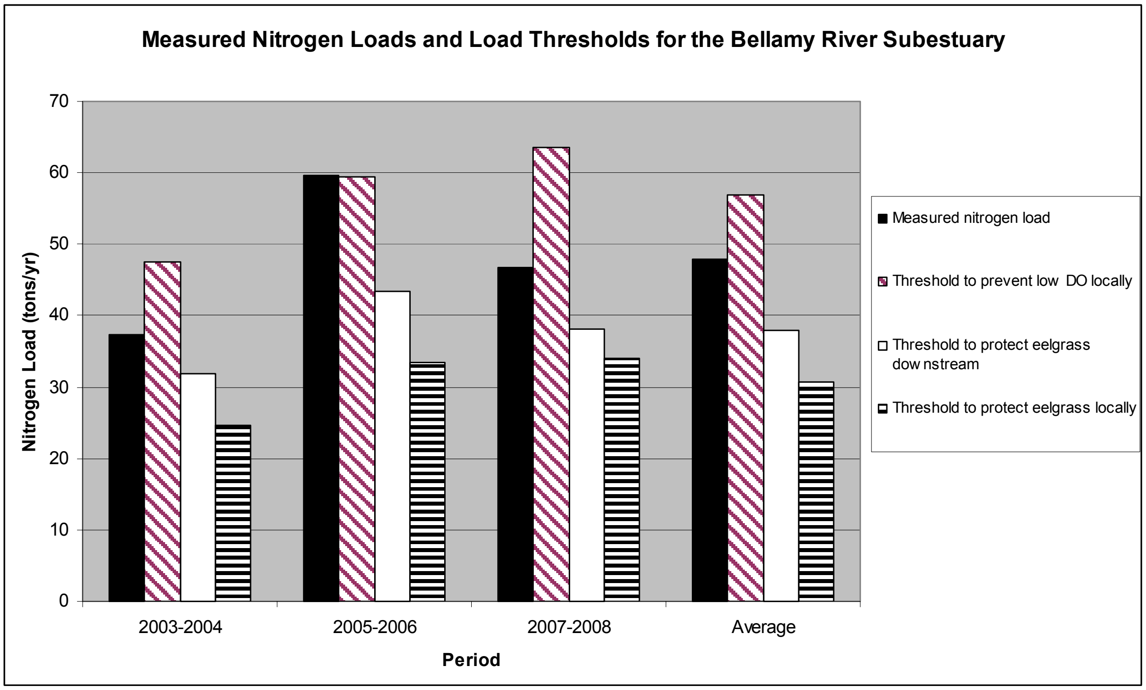


Figure 17: Measured nitrogen loads and load thresholds for the Cocheco River subestuary

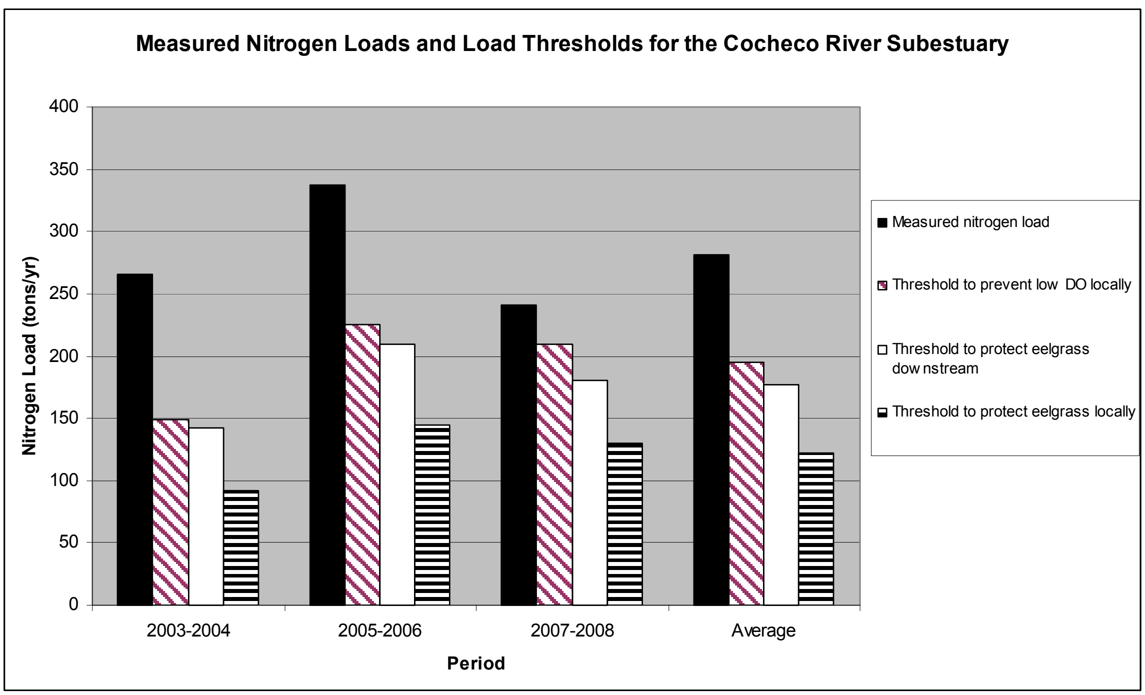
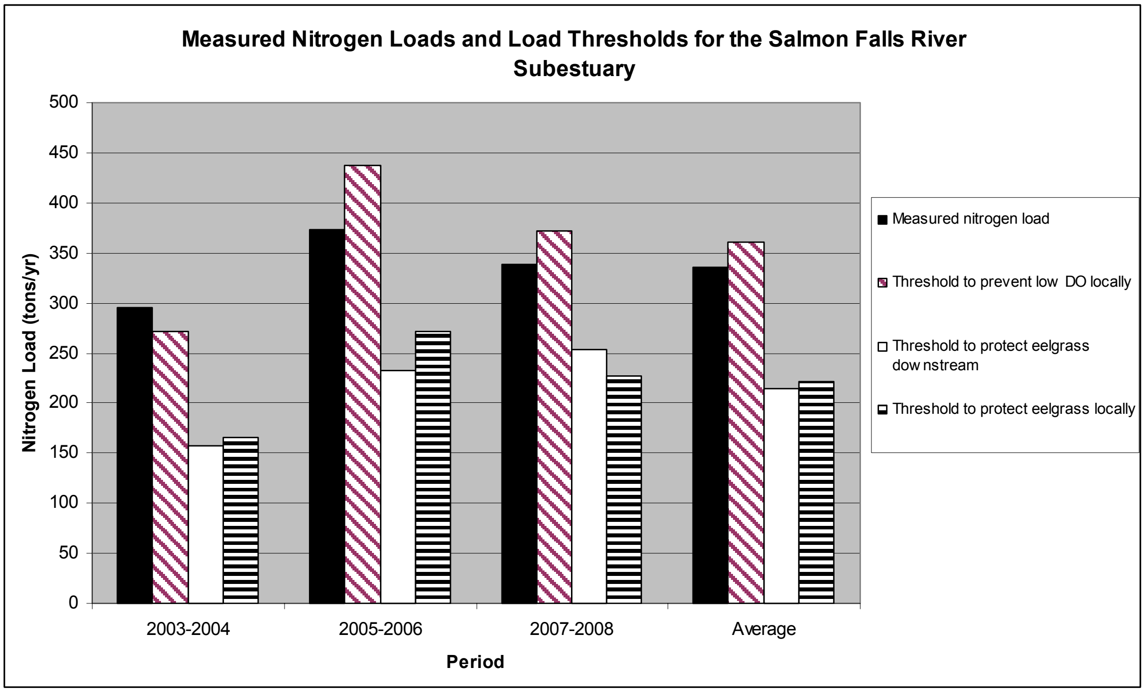


Figure 18: Measured nitrogen loads and load thresholds for the Salmon Falls River subestuary



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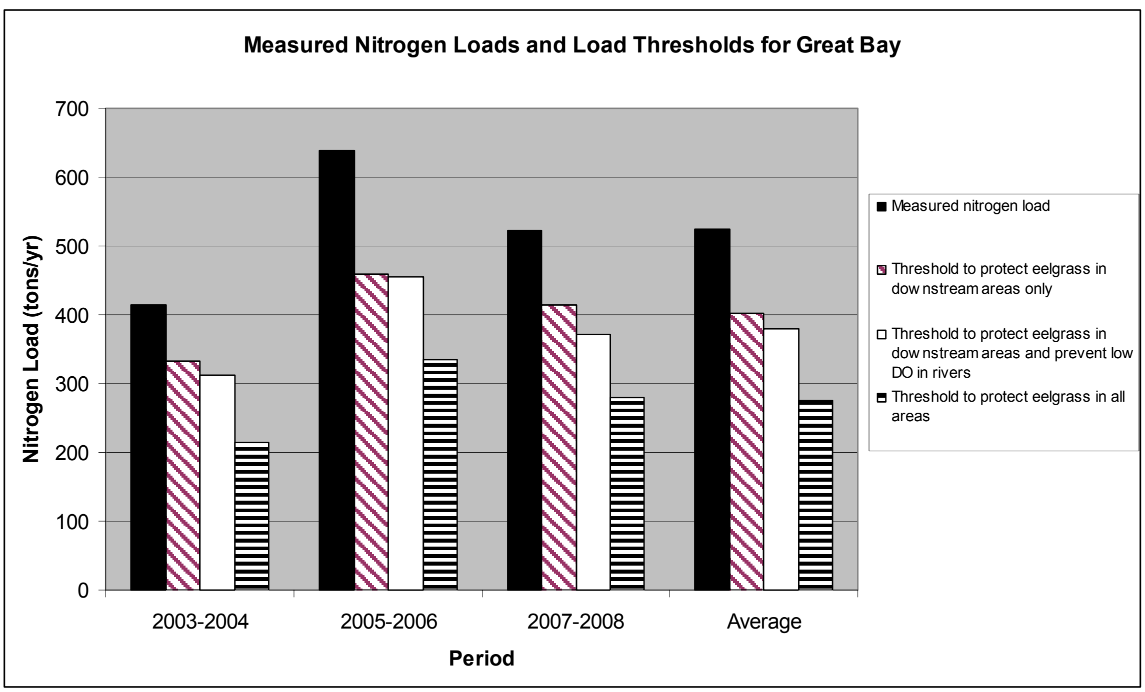

Figure 20: Measured nitrogen loads and load thresholds for the Little Bay subestuary

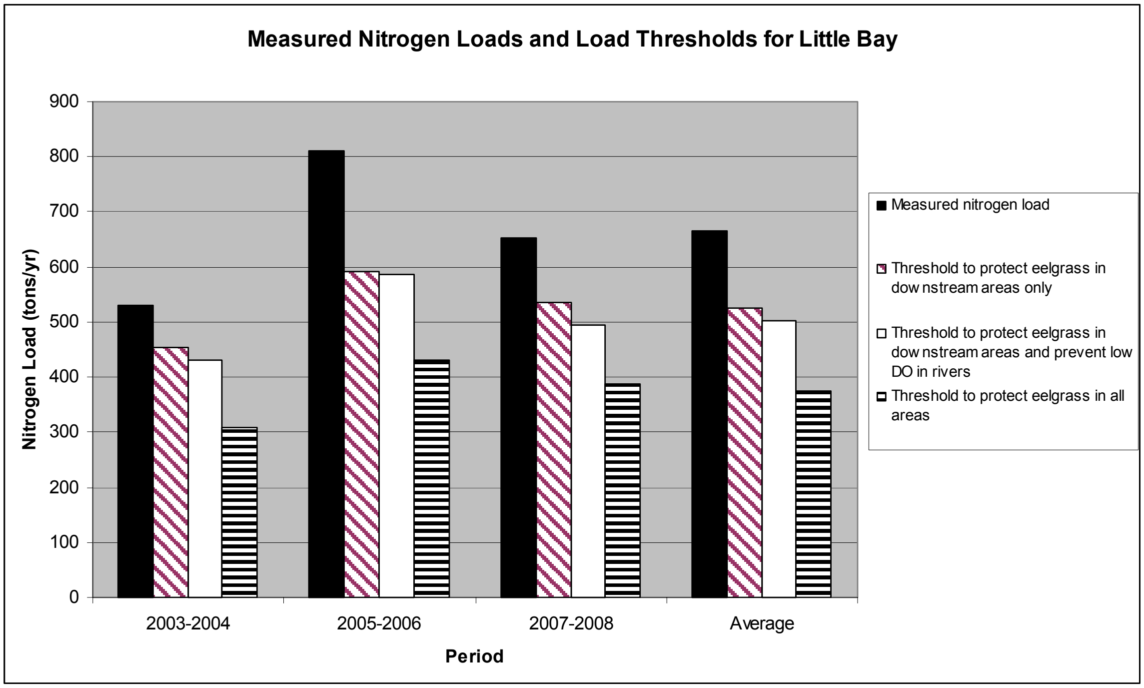

Figure 21: Measured nitrogen loads and load thresholds for the Upper Piscataqua River subestuary

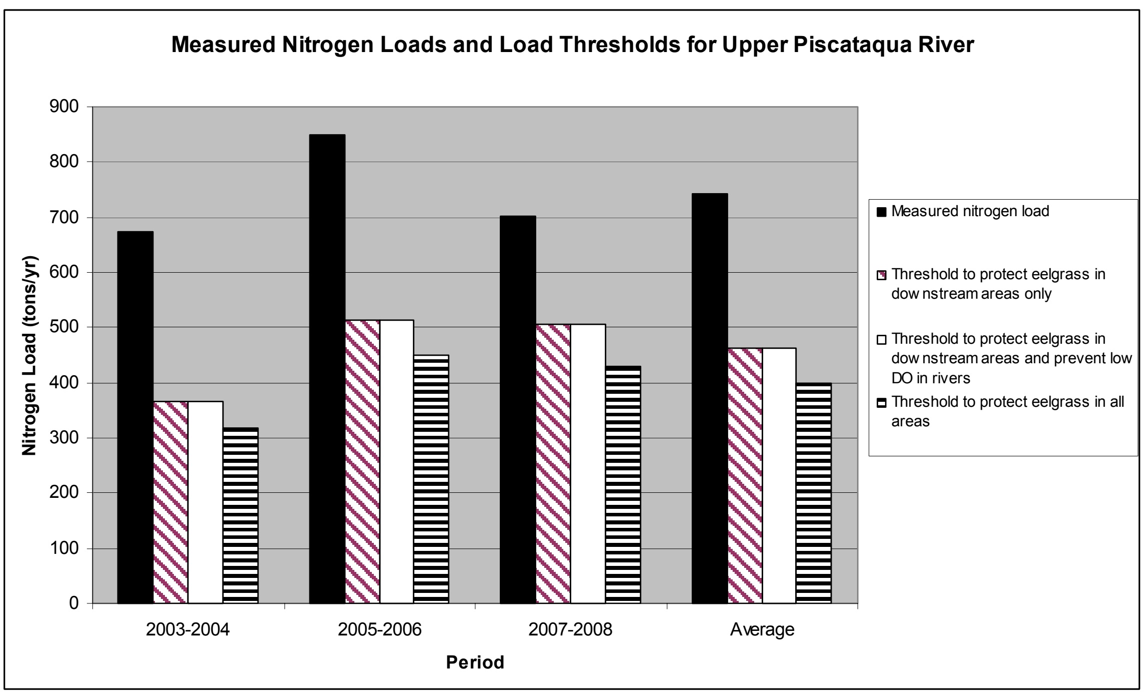

Figure 22: Measured nitrogen loads and load thresholds for the Little Bay and Upper Piscataqua River subestuaries combined